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ON
DEEP DIVING TESTS

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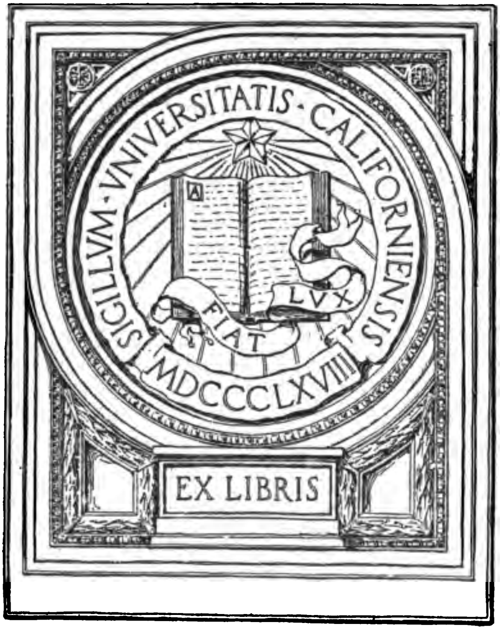
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REPORT ON
DEEP DIVING TESTS

By

Gunner G. D. STILLSON, U. S. Navy

UNDER THE DIRECTION OF THE
BUREAU OF CONSTRUCTION AND REPAIR
NAVY DEPARTMENT
WASHINGTON, D C.

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PREFACE.

The following report was prepared by Gunner G. D. Stillson, United States Navy, under the direction of the Bureau of Construction and Repair of the Navy Department. In December, 1912, a report was submitted by Gunner Stillson stating that our methods of diving were obsolete and our diving apparatus capable of great improvement. In this report he suggested that a series of experiments be made, calling attention to the procedure of diving adopted in the English Navy as a result of the long series of tests carried out by the English Admiralty in 1906–7, the result of those tests having been to make diving in great depths of water practical and safe.

Desiring to make an advance in all matters pertaining to diving, as to which there had been little improvement in our service for many years, the Bureau of Construction and Repair took this opportunity of investigating the whole subject.

To this end an exhaustive series of tests and experiments were undertaken, these comprising, first, a series of tests in a high-pressure diving tank ashore and later a number of tests in actual deep diving from the torpedo boat destroyer *Walke* in Long Island Sound. The tank used was one in the works of A. Schrader's Sons (Inc.), in Brooklyn, and by the use of this tank and the equipment furnished therewith the work of the tests was greatly facilitated.

The results of the experiments have been most satisfactory. Many changes have been shown to be desirable in our diving equipment and apparatus, and practical rules for safe diving in water of great depths have been formulated.

The bureau desires to express its appreciation of the excellent work of Gunner Stillson in carrying out these tests, and the valuable assistance of Passed Asst. Surg. George R. W. French, United States Navy, together with the good work of the chief gunner's mates whose work assisted in attaining the valuable results.

It is expected to supplement this report with a "Diving manual" which will serve as a work of ready reference and instructions for diving procedure and care of diving apparatus. This volume, however, gives a full record of the experiments undertaken and results obtained. It is hoped that it will be of interest and value to those having to do with the diving in the United States Navy. It should be carefully studied by such persons, as it will make clear the reasons for departures from previous practices and appliances and enable them to undertake diving in future with a clearer apprehension of the principles of the art.

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DEEP DIVING TESTS.

1. The following is a report of the deep-diving tests and experiments recently concluded. The entire subject of diving in the Navy, including the methods of training and efficiency of naval divers, has been investigated. The report includes statements of existing conditions in regard to the above comparisons of methods and apparatus and recommendations for improvements.

2. A summary of the conclusions derived, as a result of these tests and experiments, may be briefly outlined as follows:

(*a*) The present method of diving, as practiced in the Navy, is inefficient.

(*b*) The various types of diving apparatus in use in the Navy are, in several respects, defective and, in certain cases, constitute an element of danger to those who have to use them.

(*c*) The specifications for the manufacture of diving apparatus are inadequate and do not insure the proper material being furnished.

(*d*) The diving apparatus in use in the Navy is not standardized and, as a rule, parts are not interchangeable.

(*e*) There are no adequate regulations or instructions governing diving operations, or for the care, maintenance, and preservation of diving apparatus.

(*f*) The organization of the diving classes is capable of improvement and the course of instruction is too elementary.

(*g*) As a rule, the graduates of these classes are woefully inefficient and can not be depended upon to perform any kind of important diving work with facility.

(*h*) The qualifications of naval divers are altogether too limited.

(*i*) The conditions referred to are the result of a lack of information in regard to the subject and technique of diving and may be entirely overcome by adequate instructions, the application of more advanced methods, sufficient practice, and the use of improved apparatus.

(*j*) The efficiency of diving operations is greatly increased by properly ventilating the diving helmets.

(*k*) When a diver returns to the surface after a dive in deep water there is danger of his becoming afflicted with one or more of the various forms of compressed air illness (caisson disease) if the ascent be not properly managed.

(*l*) The pathology and treatment of compressed air illness, from which divers and other compressed air workers commonly suffer, and the physics and physiology of diving are not generally understood.

(*m*) The present available means of escape for the crew of a disabled or sunken submarine boat are inadequate.

(*n*) The present diving manual contains many erroneous statements and is greatly lacking in useful and necessary information.

3. The diving-apparatus tests and deep-diving experiments were conducted in an inclosed steel tank at the works of A. Schrader's Son (Inc.), 783 Atlantic Avenue, Brooklyn, N. Y., and in the water at the navy yard, New York.

4. The experimental tank at Schrader's factory is 10 feet high by 7 feet in diameter, inside. A cast-steel manhole cover 36 inches in diameter, held in place by heavy bolts, serves to close the opening at the top. Four glass observation windows are fitted in the shell of the tank, through which a view of the interior is afforded. The arrangement of fittings, etc., is shown in the blue print, inclosure (A).

5. In operation, the tank is filled with water to the desired level; the divers enter by means of a ladder, which is withdrawn when they reach the bottom; the cover is secured, and air pressure, corresponding to any required depth of water, is applied. The divers receive air through an ordinary diving hose coupled to a fitting riveted to the shell of the tank, as shown in the drawing. Communication to the divers is established either by electric bell, telephone, sound, or visual signals.

6. All conditions of diving were obtained in the experimental tank, with the exception of tide, travel through the water, and the effects of various kinds of sea bottoms. These latter conditions were found in the open water.

7. I also quote from a considerable practical experience in connection with various kinds of diving operations, covering a period of 10 years, after having passed through the diving class at Newport.

8. In cases where actual tests or experiments have not been possible I bring evidence to prove the various statements contained herein.

9. A comprehensive discussion of the physiology of diving is contained in Gatewood's Hygiene, and this volume may be found in the medical library on board any ship in the Navy.

10. References are also made throughout this report to the findings of the British Admiralty deep-water diving committee and the works of the celebrated English scientists J. S. Haldane, M. D., F. R. S., and Leonard Hill, M. D., F. R. S., all of which are on file in the office of the Naval Intelligence, Navy Department, Washington, D. C.

11. During the course of the investigations covered by this report a great number of tests and experiments have been accomplished. As a consecutive account of all these would be both lengthy and confusing, the report is so arranged that the various details may be considered in the order of their importance.

12. As it is necessary to consider the construction and arrangement of diving apparatus in order to comprehend the subject of diving, this question will be taken up first.

13. There are two principal types of diving apparatus in common use in the Navy. One is furnished by A. J. Morse & Son (Inc.), 221 High Street, Boston, Mass., and the other by A. Schrader's Son (Inc.), 783 Atlantic Avenue, Brooklyn, N. Y. Various modifications of the two general types have been introduced from time to time, and, while each one possesses its peculiar advantages and disadvantages, they are practically alike in operation.

14. These two types of diving apparatus are referred to generally as the Navy standard diving apparatus. This expression or reference to a standard is misapplied, for the reason that a standard diving apparatus for the Navy does not exist at the present time. It serves, however, to distinguish the Navy diving apparatus from certain commercial types, diving armor, self-contained diving apparatus, submarine-escape apparatus, life-saving apparatus, etc.

15. Diving armor may be distinguished from the ordinary diving apparatus by reason of its being designed to protect the wearer from excessive pressures of air or water, while the diving apparatus in common use simply enables a person to descend and work under water. While it is designed to prevent certain parts of the body from coming in contact with the water, it offers no protection against the effects of either air or water pressure.

16. Self-contained diving apparatus is one that contains within itself a respirable supply of air or gas, the ordinary air hose connections and diving pumps being dispensed with.

17. Special forms of diving apparatus are made for purposes of submarine escape, life saving, rescue work, fire fighting, and for use in irrespirable atmospheres.

18. A description of the diving apparatus may be found in the Diving Manual, 1905, pages 6 to 18, and in the chapter on diving in Gatewood's Hygiene.

19. The operation of the diving apparatus is as follows: When a diver goes under water, any air with which his dress is inflated is driven out through the outlet valve by the pressure of the water, so that the dress becomes closely applied to his legs, body, and arms, up to the corselet. If the valve were kept screwed up so far that the dress remained inflated under water, he would not be able to get down. The consequence of the collapse of the dress is that the pressure on all parts of the body below the helmet is greater than in the helmet. If the valve is freely open, the excess of pressure on any part of the body will be equal to that of a column of water the height of the valve outlet above this part. Thus the external pressure on the chest at the nipple will be about 1 foot of water, or 70 pounds per

square foot, above the pressure in the helmet. As the pressure in the lungs is that of the helmet, the diver will have to expand his lungs against this excess pressure; and when the experiment is tried the exertion required is found to be very considerable and breathing is greatly hampered.

20. Under ordinary conditions an experienced diver adjusts the pressure on his valve in such a way as to ease his breathing as far as possible without endangering his stability, and he may frequently have to adjust the pressure on the valve as he changes the position of his head. If, with the valve comfortably adjusted for the erect position, he stoops down for more than a short time, air accumulates in his dress and he runs the risk of being "blown up" (i. e., carried to the surface)—a dangerous accident if he is at a considerable depth. In order to stoop or crawl on the bottom he must unscrew his valve, so as to let air escape freely. If his head is nearly as low as his body, as when he is lying or crawling on the bottom, he can, however, breathe quite comfortably with the valve freely open, since the excess of pressure on the chest and abdomen is greatly diminished. This position is the most easy one for a diver.

21. Bleeding from the nose, etc., is commonly observed with inexperienced divers, and is apparently often due to the difference between the air pressure and the blood pressure in the walls of the respiratory passages being abnormally increased owing to failure of the diver to keep his valve sufficiently closed, particularly during exertion. An inexperienced diver will, for instance, often struggle up the descending line with his valve wide open, and has, consequently, a heavy weight to lift with his arms, whereas an experienced man will screw up his valve sufficiently to take the weight off his arms, and slip up the rope with practically no exertion.

22. Ten fathoms is the depth of water in which divers of the Navy are now required to qualify. At the time this limit of depth was established it was considered sufficient for naval purposes, but of late the required range of diving operations has increased with possibilities of service at considerable depths. Much dissatisfaction is caused by present methods in relation to depths of submergence considered practicable under them, and the small amount of work that can be accomplished at the depths attempted because of the untoward effects upon the divers.

23. The special difficulty associated with diving under existing conditions is that breathing is found to become more and more labored the deeper a diver descends below the surface and his power of doing work becomes thus more and more limited. This is generally and erroneously attributed to the effects of pressure.

24. The respiratory distress, which under the present conditions of diving usually prevents divers from working at more than ordinary

depths, is due to the pressure of carbonic-acid gas in the air of the helmet, and can be entirely obviated by increasing the supply of air in direct proportion to its increase in absolute pressure.

25. During these experiments no oppression of breathing was experienced by any of the men at 42.6 fathoms pressure so long as the air supply was adequate for proper ventilation of the diving helmet.

26. In the scientific publications, previously referred to, the effects of carbonic-acid gas (CO_2), the theory of ventilation of the diving helmet, and other physiological problems in connection with a diver's air supply, are clearly explained and must be included in a consideration of the diving apparatus.

27. It may be briefly stated that during the course of many experiments it has been definitely settled that for a diver to perform efficient work under water the accumulation of CO_2 in his helmet must be kept below 3 per cent for the reason that anything in excess of this amount produces respiratory distress.

28. To keep the CO_2 content of the helmet below the maximum allowable percentage, a minimum supply of air to the helmet of 1.5 cubic feet per minute is found to be necessary when the diver is at rest. During exertion this air supply may have to be increased by a third or more. As the air supply measured at the surface must increase in direct proportion to the diver's absolute pressure, the coefficient becomes $1/33 = 0.0303$ for each foot from the surface. Therefore, the minimum air supply in cubic feet per minute for any given depth may be computed by the following formula: $S = 1.5 (1 + F (0.0303))$. In which S is the required air supply in cubic feet measured at the surface, and F is the number of feet the diver's helmet is below the surface. The factor 33 is obtained from the water barometer, or the height of a column of water in feet to equal 1 atmosphere of pressure.

29. The delivery of the amount of air required depends upon the capacity of the diving air pump and the rate of pumping. Each cylinder of a pump has a certain capacity, and if with each revolution of the flywheel the piston completes two strokes, it is evident that, barring leakage, there is a fixed relation between the required air supply and the number of revolutions of the wheel. Supposing that with each turn of the wheel or each two strokes of the piston 0.1 cubic foot of air is delivered against atmospheric pressure. Then with 15 revolutions per minute the 1.5 cubic feet would be delivered at the surface. But with the diver at the depth of 33 feet or an absolute pressure of 2 atmospheres the 1.5 cubic feet at the surface would be only 0.75 cubic foot at the helmet. It therefore follows that as the air at the surface must be 3 cubic feet for the delivery at the helmet to be 1.5 cubic feet, the revolutions of the wheel must be 30 per minute for that depth. And so the number of revolutions may

be calculated for each depth. In two-cylinder double-acting pumps the cylinders may be connected or disconnected so that one or both may be in use. Thus with both cylinders in use the air supply on each revolution is doubled. Consequently if 15 revolutions with one cylinder gives the requisite air supply at the surface, the same number of revolutions with two cylinders would give the required amount of air at a depth of 33 feet. It is not easy to maintain a speed of 30 revolutions per minute with a double-acting pump against much pressure, and so as the depths increase the number of cylinders (or pumps) have to be increased that the required air supply may be delivered on from 20 to 25 revolutions after making allowance for leakage.

30. No pump is without some leakage and the amount may readily be sufficient to bring down the supply of air delivered to a point where asphyxia results. A well-constructed pump should not show a greater leakage than 20 per cent in 200 feet of water with proportionate loss for varying depths. A pump is, however, regarded as efficient when the leakage does not exceed 10 per cent at a depth of 132 feet, or 60 pounds excess (gauge) pressure. Assuming a leakage of 10 per cent at a depth of 132 feet, or 60 pounds excess pressure, to secure the calculated air supply the number of revolutions of the pump would have to be increased accordingly.

31. In order to attain to a given standard of ventilation, it is quite evident that the diving air pumps must be kept running at a certain rate. To determine the necessary rate of speed of the pumps to deliver a specified volume of air for any depth in which a diver may be working, it is first necessary to determine the efficiency of the pumps.

32. The ordinary method in use for proving the efficiency of diving pumps is quite unreliable, and many pumps in actual use, although they pass this test, are so leaky as to be unsafe. The pumps can, however, be made efficient by careful overhauling and repair.

33. For testing a diving air pump the only process at present in use is to attach a length of hose, blank flanged at the far end, to the pump, and then pump air up to a considerable pressure inside this hose and watch the gauge after stopping the pump. If the pressure only falls slowly, if at all, the pump is supposed to be tight. It is evident, however, that since the gauge is connected beyond the outlet valves, this process only tests the outlet valves of the pump and not the piston or inlet valves. It is, therefore, wholly illusory as a test of the pump itself.

34. For proving the real efficiency of diving pumps during these experiments the following test for leakage was employed: The pump was connected by means of a short length of hose to a tank of 2 cubic feet capacity. One cylinder at a time was tested, and the number of

revolutions required to bring the pressure in the tank, as indicated by a pressure gauge, up to 15, 30, 45, and 60 pounds, and so on, was noted. From a consideration of its calculative capacity and its actual performance, the percentage of leakage was easily obtained.

35. The formula used in calculating percentage of leakage of diving pumps is as follows:

When

A=Area of cylinder.
N=Number of compressions per revolution.
L=Length of stroke.
P=Pressure in pounds per square inch by gauge.
14.7=Pressure in pounds per square inch of 1 atmosphere.
C=Capacity of tank and hose.
W=Waste room in pump.
R=Number of revolutions.
T=Theoretical capacity.
V=Volume of air compressed.

$$1.\quad ANLR=T$$

$$2.\quad \frac{P\,(C+W)}{14.7}=V$$

$$3.\quad \frac{T-V}{T}\times 100=\text{per cent leakage.}$$

36. Tests of diving pumps were made on board the U. S. S. *Georgia, Nebraska, New Jersey,* and *North Dakota,* with following results:

Vessel.	Pump.	Pressure.	Per cent leakage.
		Pounds.	
Georgia	Morse	90	87
Do	do	90	65
Nebraska	do	75	100
Do	Schrader	55	100
New Jersey	Morse	85	100
Do	do	90	87
North Dakota	do	90	35
Do	do	90	36

37. These tests were made without any special overhauling of the pumps and represents the condition in which the pumps would have been had they been required for immediate use. The pumps on the *North Dakota* were in better condition than the others and this is accounted for by the reason that these particular pumps had been in service a shorter period than those on board the *Georgia, Nebraska,* and *New Jersey.* Since these tests were made, I am informed that the pumps were repaired on board ship and, later, by the manufacturers.

38. It is found, during many tests and experiments, that efficiency of a diving pump depends upon the care it receives. This is true also of all parts of the diving apparatus and, in fact, of any other material. The leather packing, valve faces, pistons, etc., deteriorate from lack of proper care, also the rubber dresses, hose, leather shoes,

belts, woolen underwear, etc., are all affected by improper stowage, etc. In many cases on board ship and elsewhere the diving apparatus receives but very little care or attention. Where it is given some thought and care the effort is usually misdirected. At the conclusion of this report are a number of recommendations which, it is believed, will, if carried out, operate to insure the proper care, maintenance, and upkeep of the diving apparatus in the Navy.

39. Six diving pumps were used and tested during these experiments. Three of them were new double-acting two-cylinder pumps furnished by A. J. Morse & Son and the others were supplied by A. Schrader's Son. One of the latter was a new one and the other two were old ones that had been repaired on contract by A. J. Morse & Son. All these pumps were carefully inspected and tested upon their receipt and were always tested before being used. Previous to the conclusion of the tests each one was run for a period of about 10 hours against a pressure of 100 pounds per square inch. The records of these tests are included in enclosures (C) to (H), inclusive.

40. In general, while there are several features of the "Morse" pumps that it is deemed desirable to change or improve upon, the three pumps tested were found to be very efficient and suitable for naval use. The objectionable features are as follows:

(*a*) The pump chest is not strong enough. When under strain of heavy pumping the case is liable to crack or be pulled apart.

(*b*) The pump-chest cover is not so hinged that it can be tilted far enough backwards. When in a boat it will slam shut if the boat pitches very much. The cover can not be locked open in any position. If in use when it is raining the cover can not be adjusted to afford a view of the working parts of the pump and at the same time keep the rain out of the pump case.

(*c*) The crank handles are too short. Sufficient men can not find room on the handles to keep the pump running at maximum pressure.

(*d*) The flywheels are too small and light.

(*e*) The water reservoir or cooling tank is not high enough to permit flooding tops of cylinders.

(*f*) The upper inlet and outlet valves and oil cup are not conveniently located. No repairs or adjustments can be made to them with pump in operation.

(*g*) The operating shaft for three-way cock is not stiff enough.

(*h*) The bottom outlet valves are not conveniently located.

(*i*) The gauges are not correctly graduated.

(*j*) The ring bolts for lashing the pump are not well secured.

41. The Schrader pumps were found to be less efficient (see inclosures (C) to (H), inclusive). This is due to a weak bed plate, lighter frame, and an inferior type of piston. The Schrader pump combines all the objectionable features of the Morse pump, excepting

the one enumerated under (*h*), and, in addition, the ones mentioned above.

42. Another objectionable point in relation to the diving pumps, and in fact all the diving apparatus, is that but few of the parts are interchangeable.

43. The British and Italian navies have adopted as standard an improved type of diving pump manufactured by Siebe, Gorman & Co. (Ltd.), London. The improvements consist in the locating of the top and bottom discharge valves and bottom inlet valves in a common casting in an accessible position at the front of the pump; increasing the length of stroke from 6 to 7½ inches; and in raising the height of the cooling water reservoir so that the tops as well as the sides of the cylinders will be flooded with cooling water.

44. The rearrangement of the valves and air channels increases the capacity of the waste room in the pumps and, consequently, decreases its efficiency. This, however, is compensated for by the increase in length of stroke. The enlargement of the cooling water reservoir is considered a necessary and desirable improvement. Previous to these changes in the Siebe-Gorman diving pump, the Morse and Siebe-Gorman pumps were practically identical. It is not believed that the British Admiralty standard diving pump is as efficient as the pump in our service. The arrangement of valves, etc., is more convenient but the loss in efficiency, the increase in weight, and the greater difficulty of operation, due to increase in length of stroke, more than offsets this advantage.

45. The construction of various types of diving pumps, including three and four cylinder single-acting pumps, more powerful two-cylinder double-acting pumps, diving pumps with suitable engine or motor-driving power, etc., have been carefully investigated and the conclusion is reached that, for ordinarily diving operations, the present design of two-cylinder double-acting diving pumps, with defects enumerated in paragraph (40) corrected, is the best suited and most desirable for naval use.

46. The single-acting three-cylinder pump can not be considered on account of its small capacity. The four-cylinder single-acting pump, if made for same capacity as the present pump, is objectionable on account of its awkward dimensions. More powerful pumps, along present designs, are impossible on account of the labor required to operate them. Diving pumps with motor or gas engine attachments are undesirable on account of their increased weight, cost, etc.

47. In cases of necessity, where the capacity of a single diving pump is insufficient for the operation in hand, the volume of air being delivered to the diver may be increased by connecting two or more pumps together by means of a special junction piece or manifold, and cutting in additional cylinders as necessary. It is found during

actual tests to over 30-fathom pressure that, with a minimum amount of leakage in the pumps, an additional cylinder is required for each additional atmosphere of pressure to which the diver may be subjected.

48. The manual labor required to heave round the pumps increases with the depth of submergence much more rapidly than the increase in pressure and to such an extent that diving operations with manually operated pumps are limited to depths beyond which divers can work with ease. The use of a number of pumping units is impracticable except under the most favorable conditions, and the tests were so unsatisfactory in this regard that it was imperative to turn to some other means of air supply.

49. As most naval vessels are equipped with elaborate compressed-air systems, the idea of utilizing the output of these power-driven compressors for diving operations presented itself. Practical tests have been carried out with complete success and all the necessary details have been worked out.

50. The low-pressure air lines of nearly all ships carry a pressure of about 100 pounds per square inch, which is sufficient air for a diver in about 175 feet of water (5½ atmospheres), the difference in pressure being necessary to insure a proper circulation through the diving helmet. For greater depths connection can be made direct to a high-pressure or torpedo air line by means of suitable reducing valves. The air is led through an ordinary torpedo air separator and if possible through an accumulator or reservoir, to insure a reserve supply in case of accident, direct to the diver. A special form of control valve (inclosure I) is introduced in diver's air hose, convenient to the diver, and he controls his supply of air independent of any assistance at the surface.

51. I am informed indirectly that while attempting to dive in a similar manner a diver on one of the boats of the Atlantic Submarine Flotilla recently lost his life. Rumor has it that the control valve was operated at the surface. It is quite evident that such practice can only be attended with the greatest of danger to the diver and should be strictly prohibited. By reference to the correspondence from the naval attaché, Berlin, to the Director of Naval Intelligence, dated May 13, 1914, relative to diving in the German Navy, it will be seen that the German Navy has adopted the compressed-air system of diving for use in deep water. Its advantages, etc., are very clearly explained, but, for some reason not explained, they provide for surface control of the diver's air supply, which is considered dangerous practice.

52. This method of diving provides an economical means for conducting shallow as well as deep diving operations from torpedo boats, destroyers, and submarines, which vessels are not at the pres-

ent time furnished with diving apparatus. In cases where it may be desirable to dive at a distance from a vessel, one or more torpedo air flasks, charged to full pressure, can be utilized to carry an air supply sufficient for a considerable length of time for one or more divers. Connections from a torpedo air flask to the reducing valves on the diving manifold should be made by means of high-pressure flexible-copper tubing, such as a regulation torpedo air-charging pipe. Care must always be taken that air furnished for breathing purposes is clean and free from toxic or noxious fumes.

53. *Diving helmets.*—Several different types of Morse, Schrader, Siebe, Gorman, and Draeger diving helmets were tested and experimented with. The conclusions derived are as follows:

(*a*) The bolt type of diving helmet, now in common use in the Navy, is much inferior to the interrupted screw type. The bolt helmet should be abandoned, in preference to the latter, as has been done by all European navies and commercial organizations throughout the world. The principal objections to the bolt helmet are that it is too heavy and awkward. The heavy flanges at the neck piece are too high and consequently cause an ill-fitting helmet. The hinged securing bolts take up much room and interfere with important fittings.

(*b*) The interrupted screw type of helmet is superior to any other; permits a better shape; can be made lighter; is more easily secured and removed; necessary fittings can be more conveniently located; and a narrow breastplate can be used.

(*c*) The lock type of helmet is too complicated and is not considered desirable for naval use.

(*d*) The regulating escape valves on all helmets now in service are improperly constructed and inconveniently located. The range of adjustment is too limited, and in cases of emergency this defect is liable to constitute a serious danger.

(*e*) An additional or supplementary relief valve, known as a "spit cock," should be installed on all diving helmets. Such a valve is of great value and importance, as it is necessary quite frequently to make finer adjustments to the diving apparatus than is possible by present means.

(*f*) Air channels on the inside of diving helmets for directing the flow of exhaust currents of air are unnecessary.

(*g*) Hinged faceplates should be substituted for those of the screw type.

(*h*) Hinged circular fair leaders for hose and life line attached to the neck piece of breastplate should be substituted for present type of eye pads on helmet.

(*i*) The studs on the front part of the breastplates for securing breast and back weights are unnecessary.

(*j*) The shape of the wing nuts for securing dress to breastplate should be changed to conform to the latest improved pattern.

(*k*) The four segmental straps and 12 studs on breastplates are found superior to any other method for making a neat, water-tight joint between diving dress and breastplate.

(*l*) The methods of making telephone connections to diving helmets are impracticable. Telephone cables should be readily attachable and detachable.

(*m*) The side windows of diving helmets should be made round and located more to the front in order to facilitate better vision of objects outside the helmets.

(*n*) The diameter and height of the Navy helmet should be increased to give the diver sufficient room to move his head freely while wearing the double receiver type of diving telephone.

54. The feature of a narrow breastplate is most important and adds much to the safety and efficiency of a diver. All the breastplates now in service are too wide across the shoulders. A wide breastplate prevents a diver from reaching over his head. During my own experience, while working under the bottom of the U. S. S. *Georgia*, in Provincetown Bay, 1911, I came near suffering a fatal accident from this cause. I was holding on to a line with one hand, at the turn of the bilge near the starboard after quarter, when the diving dress suddenly collapsed from an insufficient air supply. The width of the breastplate prevented me from getting a hold with my other hand, from signaling for more air or from reaching the regulating valve. If I had let go or my attendants had not held my lines a fall of 60 feet to the bottom would have been the result. My strength soon became exhausted and I was forced to let go. Fortunately the alertness and expertness of my assistant saved me. He had sensed the danger of a fall and had the slack of my lines well in hand. This incident is mentioned merely to illustrate one disadvantage of a wide breastplate. All the weight of a diving apparatus, excepting the shoes, is carried on or suspended from the breastplate, and it was formerly considered necessary that the breastplate should be made wide so that it would rest comfortably on the shoulders. An experienced diver, however, adjusts the inflation of his dress in such a manner that the weight of the apparatus does not bear uncomfortably on his body.

55. It was found from inquiry among many naval and professional divers that they were a unit in condemning the location of the regulating escape valve on diving helmets. It is especially awkward to the amateur diver. The general inability to reach the valve under all conditions creates a feeling of insecurity that is very objectionable. Inquiry among the manufacturers of diving apparatus discloses the fact that there are no well-defined reasons or rules for various prac-

tices in the construction of diving apparatus, and the faults alluded to are the result of cut-and-dry methods.

56. As a result of numerous tests and experiments an improved regulating escape valve has been designed which eliminates all the objectionable features of the older model and incorporates certain new and desirable improvements. See sketch and description, inclosure (J). Practical trials of this valve have been most successful.

57. To determine the proper height of the helmet air-exhaust opening, regulating air-escape valves were located and tested in many different positions on the helmet. It was found that, with the exhaust opening too high, breathing becomes very difficult if the valve is freely opened or the air supply is insufficient. With the valve in such a position (toward top of helmet) under ordinary conditions of diving, it must be partially closed to secure adequate inflation of the diving dress. Consequently, as the pressure is increased within the dress, the volume of air being delivered is decreased, and an improper ventilation follows. A lowering of the exhaust opening improves conditions, unless it is carried to the opposite extreme, in which case it will produce positive buoyancy and cause the diver to lose his hold on the bottom. The correct location was found to be at a point near the joint formed by the helmet and the breastplate, or where the capacity of the helmet above the exhaust opening is not less than 600 cubic inches.

58. All diving helmets now in use are fitted with some sort of an air channel for directing the flow of exhaust currents of air. As is well known, the expired breath is warm, charged with aqueous vapor, and is lighter than atmospheric air; hence, in an inclosed space, such as a diving helmet, it tends to rise to the top of the helmet. However, as the fresh-air current enters the helmet with considerable velocity and its course is deflected by the curved walls of the helmet, it is apparent that the particular manner in which the exhaust air is led from the helmet is unimportant. Chemical analysis of samples of air taken from various parts of the helmet under various conditions of diving showed no variation in the percentage of CO_2 content. Much of the diving during the tests and experiments covered by this report was accomplished with the exhaust-air channel entirely removed from the helmet. No matter what the arrangement of the exhaust channel was, no difference could be detected in effects upon the diver, the action of the diving apparatus, or in the chemical analysis of the air contained in any part of the helmet.

59. If it were necessary, the air space within a diving helmet could be divided so that the diver would inspire directly from a portion of the helmet containing fresh air and expire into a space open to exhaust only. In this manner the volume of air necessary to be supplied to a diver under ordinary conditions could be diminished by

three-fourths. The disadvantage is that it would make the helmet more complicated and interfere with telephonic communication and is, therefore, not recommended.

60. In connection with the tests of the exhaust-air channels, etc., similar tests and experiments were made in regard to the manner of entry of the fresh air. Various arrangements of valves, piping, airways, etc., were tried and tested. The present method of air inlet could not be improved upon and no change is recommended. In my report, No. 38–T, April 21, 1914, paragraph 10, it was stated that a helmet receiving air in the breastplate was considered very efficient. It has since been discovered that the efficiency referred to was not the result of the peculiar arrangement of the air inlet but was due to the quality and volume of air received. It is immaterial how the air enters the helmet as far as adequate ventilation is concerned, but convenience in construction and safety in use indicate the present arrangement to be more satisfactory than any other.

61. A hinged faceplate is found more convenient than the screw type. The threads on the latter, or in the helmet, frequently become burred, and means are not always at hand for repair. Also, the detachable faceplates are occasionally lost overboard and are the cause of much delay. The hinged faceplate makes a perfectly tight joint, is easily secured or opened, and is altogether more satisfactory.

62. *Diver's telephones.*—Ten different types of diver's telephones, and all the different combinations of these, were tested and experimented with, including the following: Morse—Navy, commercial, and special; Schrader—Navy and special; Siebe-Gorman—single and double diver's.

63. It was found that, under ordinary conditions of diving, the present Navy diving telephones are useless. Two kinds of diving telephones, namely, Morse and Schrader, are now furnished to ships and stations. The Morse phone consists of a single receiver and transmitter permanently installed in the helmet. The tender's instrument is mounted on a convenient hand grasp. The battery (6 dry cells) is contained in a leather case so shaped and fitted with straps as to be carried by an attendant or slung over his shoulder. The connecting cable is led through a fair leader and stuffing box into the helmet and permanently connected to the diver's receiver and transmitter. The surface end of the cable is fitted with special lugs for connecting to an attachment on the battery case. The instruments are connected in series and provision is made for connecting the phones of two divers and an attendant together. The arrangement of the Schrader telephone is similar to that of the Morse type, except that the diver's instrument is formed into a combination transmitter and receiver and held in a detachable metal case screwed to the helmet.

64. None of the ordinary single-receiver diving telephones operate efficiently under water, for the reason that the noises in the helmet, caused by the inblow and escape of air, interfere with conversation to such an extent that communication is not possible. Under some conditions the diver can be heard but, as a rule, he can not hear or distinguish what is being said to him. If the noises in the helmet could be momentarily eliminated, by shutting off the inflow of air, communication would, under favorable conditions, be possible. No such provision, however, for shutting off the air supply is provided.

65. The British and Italian navies have adopted, as standard, an improved diver's telephone manufactured by Siebe, Gorman & Co., London. This type is of the single-receiver loud-talking kind and was found to be very efficient in connection with apparatus using a restricted air supply, such as self-contained diving apparatus, etc. In the deep-water diving tests the same trouble was experienced with noises in the diving helmet as mentioned in the case of other single-receiver types of divers' telephones. Aside from this defect the Siebe-Gorman type of diving telephone equipment is excellent.

66. The Draeger and the special diving telephones submitted for test by Morse and Schrader were tested and found more or less satisfactory in operation and unsatisfactory in certain points of construction, adaptability, etc. Draeger and Schrader phones are of the single-receiver type and subject to the faults common to this arrangement. The efficiency of the instruments was much increased by making parallel connections and partially shutting off the diver's air supply. Far superior, however, to any other type of diving telephone previously tested was the Morse commercial type. This is fitted with double receivers, which are held over the diver's ears by a suitable headstall.

66. The Morse commercial diver's telephone and various types of Navy fire-control telephones were tested with complete success. The problem of telephonic communication to divers in any depth of water was finally and definitely solved by the use of double receivers, fitted with large flexible-rubber earpieces to exclude the helmet noises, and special electrical connections, as shown in the sketch, Inclosure K.

68. Aside from the defects in the telephone instruments it was found that the battery boxes, telephone cables, and connections are unsuitable for the purposes intended. The battery boxes are now made of leather and shaped and fitted to be carried by an attendant. In practice the box is never carried and such provision is unnecessary. A hardwood box to contain the dry batteries, provide storage for instruments, and fitted with proper connections and switches has been found more convenient, satisfactory, and

serviceable in every way than the leather telephone case. A more flexible and better protected telephone cable is a necessity, and a special form of combination telephone cable and life line has been found to be most convenient and satisfactory. The combined cable and line is more expensive, more difficult to repair, and requires greater care than is the case with separate lines, but these points are more than made up for in convenience and efficiency. A similar arrangement has been adopted in European navies after many years of practice and careful investigation. It has been suggested that the telephone conductors be inserted either in the fabric or bore of the air hose. For many and various reasons this method is objectionable.

69. The telephone cable must be readily attachable and detachable to and from the battery box and the diver's helmet, otherwise it becomes unmanageable, due to turns, kinks, etc. When deep diving is undertaken provision must be made for connecting two cables together and for making a water-tight joint. For details of telephone cable, connections, etc., see sketch and description, Inclosure L.

70. *Diving lamps.*—The standard Navy diving lantern was found to be of very efficient construction and suitable for use in deep water. The length of cable supplied should be increased from 125 to 250 feet. At present a special diving lamp of 150-candlepower is used as a standard. Ordinary 100-watt Mazda lamps are equally as efficient and less expensive.

71. A special form of diver's self-contained hand lamp, manufactured and submitted for test by Siebe, Gorman & Co., was found to equal the claims of the manufacturers but is not considered suitable for naval use. For description and details of test see inclosure (M).

72. *Diving dresses.*—The diving dresses now in common use in the Navy are very efficient and satisfactory as far as strength, durability, materials, and workmanship are concerned. The following changes in construction and design, however, are necessary:

(*a*) Standardize dimensions.

(*b*) Make sleeves longer and narrower at the shoulder to enable a diver to raise his arm in a vertical position without straining.

(*c*) Increase length of dress between armpits and crotch so a diver can bend forward without straining.

(*d*) Add provision for lacing up legs.

(*e*) Stamp date of manufacture on rubber collars and cuffs.

73. The popular idea that a rupture in a part of the diving dress is necessarily dangerous is a mistaken one. The purpose of the dress is to protect a diver from the effects of cold and dampness. If the proper precautions are observed, a man could dive as well without a diving dress as with one. He is, however, more comfortable, and can remain submerged a longer period, with one, especially where

the temperature of the water is cold. The fear of small leaks in a diving dress is groundless so long as the air supply is adequate. To determine the effects on a diver, tests were made by rupturing the dress purposely while the diver was under high pressure. He simply got wet. It was attempted to blow up a dress by excess air pressure and by sudden decompression. If the dress is in any kind of fair condition, it cannot be accomplished under ordinary working conditions, provided the diving gloves are not securely fastened. Any excess of pressure within the dress is exhausted from the ends of sleeves or at the cuffs. A dress will stand a considerable internal pressure and there is little danger ever to be expected from the possibility of its bursting from this cause. It often happens that a dress is torn or ruptured by a mechanical injury, but there is no record of a case of drowning from this cause when the air supply remained intact and the diver maintained an erect position. (*See sketches, page 105.*)

74. *Canvas overalls.*—The canvas dress overall, to my knowledge, is never used and should be abolished. The chafing pants, canvas overall, are necessary and desirable. The suspender straps should be made adjustable and to fasten in front with brass buckles in place of buttons as at present. The legs of the chafing pants should be made to lace up tightly. The chafing pants not only serve to protect the diving dress from chafe but also to regulate the distance between the breastplate and crotch and prevent the helmet from receding over the diver's head.

75. *Helmet cushions.*—Two kinds of helmet cushions are in common use. The Morse cushion is made square and fitted with tie-ties to be fastened under the armpits. The Schrader cushion is simply made round like a washer. The round cushion is more desirable because it can not get out of place or become uncomfortable if it changes position.

76. *Crinolines or shackles.*—It has been found that the crinoline is a useless and dangerous encumbrance and its use should be abolished.

77. *Diving gloves and mittens.*—The present forms of diving gloves are cumbersome and prevent a diver from properly manipulating his regulating valves, and are therefore a source of danger and should be abolished. A special glove has been designed which is satisfactory and should be issued in lieu of the article now in common use. For description and sketch see inclosure (N).

78. *Cuff expanders, tools, etc.*—In general these articles are excellent. Changes in dimensions of certain wrenches are necessary to accommodate changes recommended to be made in various parts of diving apparatus.

79. *Air hose.*—The diving air hose being furnished the Navy is excellent, and no changes are necessary.

80. *Air-hose couplings.*—Air-hose couplings furnished by various manufacturers differ in construction and in the manner of attachment. To insure a standard of efficiency and strength, it is recommended that the design for these fittings shown on sketch, inclosure (O), be adopted.

81. *Diving weights.*—At present two styles of belt-pattern diving weights are in use. A combination of the desirable features of each type and the elimination of the undesirable features are embodied in a design as shown in the sketch, inclosure (P). The Morse diving belt is too wide and nonadjustable. The Schrader belt is fitted with too narrow straps and a poor design of buckle. Diving belts have been discarded in most European navies, but careful tests have proved that the belt weight, especially for deep diving, is preferable to the heart-shaped or horseshoe-pattern lead weights. The belt gives a better balance to the diver, but the lead weights are more comfortable. In either case, if working in a strong tideway, additional weight is necessary, for which reason it is recommended that both types be furnished.

82. *Diving shoes.*—An improved type of diving shoe was tested and found very satisfactory. This shoe is made with an inner wooden sole, in addition to the lead sole, and is fitted with a brass toe cap. The wooden sole causes the shoe to keep its shape under all conditions and the brass toe cap provides protection where it is most needed. In addition to the securing straps, eyelets are fitted for lacings which are very necessary. The shoe is very comfortable and in every way superior to the article now in use.

83. *Diving knives and belts.*—The present type of diving knife and scabbard are not suitable for naval use. The knife has a double edge and is held in its case by a screw joint. A single-edged knife, flat case, and bayonet catch or lock are recommended. A knife is an important part of a diver's equipment and no descent under water should be permitted without one. In deep diving the diver has cause to fear getting fouled. During a recent diving operation in connection with salving the wreck of a sunken submarine in England an English diver fouled his life line and hose in opposite directions and died from the effects of exhaustion due to prolonged exposure. Had he severed his life line and followed up the lead of his air hose he could easily have cleared himself.

84. *Woolens.*—The quality of woolen underwear and stockings furnished is satisfactory for use in moderate temperatures. Six sets are provided with each outfit. For use in cold climates half this number should be of a better and heavier grade. Woolen wristers and caps and cotton handkerchiefs are unnecessary, and the issue of these articles should be abolished. The woolen mittens now fur-

nished should be abolished and a suitable woolen glove provided instead.

85. The miscellaneous items of diving equipment not mentioned are satisfactory. Certain items mentioned in the recommendations at the conclusion of this report should be added to each set of diving apparatus for the reasons set forth in the recommendations.

86. *Self-contained diving apparatus.*—Three different kinds of self-contained diving apparatus were tested and found unsuitable for naval purposes. These included two types (injector and noninjector) manufactured by Siebe, Gorman & Co., and one type (injector) made by the Draeger Oxygen Apparatus Co.

87. In general, the objectionable features of self-contained diving apparatus are as follows:

(*a*) They are complicated and easily get out of order.

(*b*) Their successful operation requires a degree of expertness not usually found among ordinary divers.

(*c*) The depth of water in which they can be safely used is too limited.

(*d*) The duration of time they can be used under water on one charge is too limited.

(*e*) Means for charging the compressed-air and oxygen cylinders are not always available.

(*f*) For renewing the air purifiers a supply of potash, caustic soda, or prepared cartridges, as the case may be, must be kept on hand. This material does not keep well at sea and is a source of extra expense and trouble.

(*g*) In other than very shallow depths of water a diver can not perform continual hard work on account of the distressing effects due to an accumulation of carbonic acid gas in the helmet.

(*h*) There is danger of oxygen poisoning to any but specially trained and expert divers.

(*i*) A self-contained diving apparatus is not safe when the diver has to enter a tight place or where there is danger of his becoming fouled or his ascent to the surface liable to be interfered with.

88. *Injector type*—Siebe, Gorman & Co.—The apparatus consists of diving helmet and dress in combination with steel cylinders containing oxygen and atmospheric air (50 per cent oxygen) at 120 atmospheres pressure, and a box jacketed with air to prevent loss of heat and containing cartridges of caustic soda. The granulated soda is arranged in trays, and in such a way that the air current passes over each tray. The cylinders and connections are carried by the diver in place of the ordinary back weight. The oxygen mixture escapes through a reducing valve at the rate of 5 liters per minute, and then through an injector apparatus set on the inlet tube leading to the

helmet. The force of the oxygen acting on the injector sucks the air from the helmet through the outlet pipe and soda cartridge, and frees the air so drawn from the exhaled CO_2. The supply lasts about an hour, and the diver keeps in touch with the surface by means of a combined life line and telephone cable. A by-pass is fitted, whereby in event of the reducting valve failing the diver is enabled to supply air from the cylinders independent of the reducing valve. Any excess of air that accumulates in the dress escapes automatically. The ordinary diving shoes are worn, and also, in lieu of other front weights, a small cylinder that contains a reserve supply of air, which is used for inflating the dress during descent or after the supply in the main cylinders is exhausted. A gauge in the helmet indicates the pressure of air in the main cylinders and enables the diver to know when the air supply is becoming exhausted.

89. During the tests of this apparatus it was found that the diver suffered severely from the effects of CO_2 when hard work was undertaken. The apparatus is more awkward than the ordinary diving apparatus and requires special care to keep joints, etc., tight. The valves on the oxygen and air cylinders occasionally leak, which defect causes considerable inconvenience, especially if the leakage is discovered at a distance from the charging plant. The air-purifying arrangement does not operate as it should, and altogether the apparatus is found unsatisfactory for general issue to ships and stations.

90. *Noninjector type*—Siebe, Gorman & Co.—The noninjector type, self-contained diving apparatus, is of simpler construction than the injector type, there being no injector with its fine orifices and consequent risk of choking, and less gear to get out of order. With this type the diver wears a mouthpiece, through which he exhales direct into the caustic-soda chamber. The exhaled air, after passing through the chamber, returns to the helmet purified of its CO_2. Unlike the injector type, should the oxygen supply fail for any reason, in this apparatus the purifying process goes on, and as, under these conditions, there is sufficient oxygen in the air remaining in the dress, he is given ample time in which to reach the surface. To illustrate the advantage of this particular feature I may mention a diving experience I had while using an injector type of Siebe, Gorman & Co.'s apparatus in placing explosives on the deck of the wrecked Norwegian bark *Orillano*, in 78 feet of water, off Barnegat, N. J. My air supply became completely exhausted while I was on the deck of the wreck. I was immediately and seriously affected by the CO_2 in the helmet. In order to reach the surface I had first to work my way out from among a mass of tangled wreckage and then get clear of the ship's lower rigging before it was safe to signal to be hauled up. This I was barely able to accomplish before losing consciousness. There was no relief diver or spare apparatus at hand. Had I lost my sense of

direction or made the slightest mistake in retracing my steps or become fouled in any manner, the result certainly would have been fatal. On the other hand, had I been using a noninjector apparatus the chances in favor of a safe ascent would have been much increased.

91. During the tests it was found that the noninjector apparatus was more difficult than the injector type to learn to operate. With the injector, after the valve on the oxygen cylinder is opened, the action requires no more attention on the part of the diver than the ordinary diving apparatus. When using the noninjector type the diver must inspire air from the helmet through his nose and must expire from his mouth into a tube leading to the purifier. This operation must be performed involuntary and requires practice to learn. There is no gauge provided to indicate to the diver the volume of air remaining in the cylinder, and he has to depend upon the cessation of the hissing sound of the air as it enters the helmet to tell when the air supply is exhausted. The supply is supposed to last about an hour, but this time can not be accurately depended upon for the reason that the cylinders occasionally leak and do not always contain the volume of air they are supposed to. Means for testing and checking the contents of the cylinders and for testing the adjustment of the reducing valve are not provided. Neither is any provision made for grinding valve faces or truing up valve seats of the oxygen cylinder valves.

92. If used exactly as per the instructions supplied by the makers this apparatus will function as is claimed for it. On account of the noninjector feature an expert can considerably increase the working capacity of the apparatus by manipulating the oxygen valve and allowing the right amount of oxygen to enter the helmet. The oxygen requirements of a diver vary under different conditions of work, as does the respiration. His only guide in regulating his air supply is his physical well-being. Considerable experience is necessary before he can recognize oxygen troubles which usually occur with very little warning. Experience in recognizing the symptoms incident to oxygen deficiency is acquired by being subjected to a short supply of oxygen in the presence of trained observers, having attention called to unfavorable conditions, and by noting the resulting effects and sensations. It is important that the subject be familiar with the early symptoms of oxygen shortage and be able to diagnose his condition and apply the remedy before anything serious can happen.

93. Dr. Haldane says, in his article on self-contained apparatus, that—

> if the oxygen percentage is allowed to fall gradually, while the CO_2 is absorbed, consciousness is sometimes lost without any warning symptom. In most persons, however, there is a distinct increase of breathing, and some subjective uneasiness, before consciousness is lost. As a rule the first objective symptom is failure of the limbs.

After paralysis of the limbs the senses fail one by one, the sense of hearing being apparently the last to disappear. Probably the power of thinking and acting rationally is in reality affected first of all. The subject always imagines that he is all right, just as does a man suffering from alcoholic intoxication. In reality he may be acting in a blindly irrational manner, and is very apt to be possessed with the fixed idea of going on with what he is doing regardless of the threatening danger. If with the helmet containing a mixture of oxygen and nitrogen, the oxygen supply were suddenly cut off, as has often happened, it is evident that the diver would be in imminent danger. For the oxygen percentage in the air breathed would rapidly fall, until less than 10 per cent of the oxygen were present at which point dangerous symptoms would develop rapidly.

94. From this it is apparent that noninjector apparatus is dangerous if the diver, through confusion or accident, should close his oxygen valve and neglect to open it. The circulation of air within the apparatus would continue, the CO_2 absorption would continue, and the oxygen percentage would rapidly diminish. Unless the diver was experienced and alert he would simply lie down and die without a struggle. On the other hand, if he were using the injector apparatus, the circulation of air within the apparatus would cease as soon as the injector stopped working, and the rise in CO_2 percentage would immediately warn the diver, by unmistakable symptoms, before there would be any danger from deficiency of oxygen. Thus he would be given time to make an attempt to reach the surface or to warn his assistants of his predicament.

95. In the noninjector apparatus the purifier is simply a box filled with caustic soda in stick or lump form. The expired air is forced through in the right direction by the diver expiring into the tube leading from the helmet. This puts a little extra work on the lungs but no distress was noticed from this cause. As the stick soda presents a comparatively small surface for absorption, it soon becomes coated with carbonate and bicarbonate of soda, and the absorption of CO_2 then becomes imperfect, at least during work. This feature naturally detracts from the efficiency of the apparatus.

96. In general, the noninjector apparatus is the most efficient of the three types of self-contained apparatus that were tested. The manufacturers, in their claims for the apparatus, are very conservative and while their statements are true, the device has its faults and is not recommended.

97. *Injector type, Draeger self-contained apparatus.*—The Draeger apparatus, while differing in construction and appearance, is similar in active principle to the Siebe, Gorman apparatus, injector type. The apparatus furnished for test was provided with a reducing valve set to supply oxygen at the rate of 2.5 liters per minute. When this apparatus was purchased the specifications stipulated that it should be suitable for use in 90 feet of water, and it does not meet this requirement satisfactorily.

98. The construction is such that difficulty is experienced in keeping the several joints in the piping and tubes perfectly tight. The dress is of light material and does not wear well. The regulating escape valve is complicated and difficult to overhaul. The continental form of helmet is used and is made of very light copper and will not stand rough usage. Aside from these details the apparatus was quite efficient at pressures not exceeding 1.5 atmospheres, and while using pure oxygen in the cylinders. At a depth of 90 feet of water the apparatus is not efficient.

99. In view of the fact that 2.5 liters of oxygen per minute was found insufficient for hard work, no tests were conducted at high pressures with a lesser supply which would have been necessary to keep the oxygen percentage at a safe limit. According to the records in this division a representative of the Draeger Apparatus Co., on one occasion, used this apparatus at a depth of 105 feet of water for a period of 1 hour and occupied an additional 20 minutes in ascending. He remained at rest and previous to the descent installed a special reducing valve of larger capacity. The test was of no particular value, other than to demonstrate the skill of the diver, as it was not accomplished under service conditions. Had he been required to perform a stipulated amount of work the result would have been different.

100. During the tests of the Draeger apparatus, Diver Drellishak was sent in the tank with it, subjected to 1.5 atmospheres of oxygen pressure, and required to lift a box containing about 40 pounds of lead weight from the bottom of the tank to a point about the level of his hemlet (as high as he could reach) several times in succession until he became tired. He was then allowed to rest a few minutes and afterwards required to repeat the operation, etc. In less than 20 minutes he was suffering severe distress and in danger of collapse. Chemical analysis of the helmet air, taken during test, showed an increase in the CO_2 percentage but not sufficient to have caused a tendency toward loss of consciousness. Insufficient oxygen is ascribed as the cause of part of his troubles.

101. The various types of self-contained diving apparatus could probably be improved so that they would fulfill certain requirements but can never be made to equal the efficiency of the ordinary diving apparatus in its improved form. For naval purposes, no circumstance or condition, in connection with probable diving operations, can be conceived wherein a self-contained diving apparatus would be more desirable than the standard diving apparatus.

102. *Submarine escape apparatus.*—The Draeger submarine escape apparatus was tested and found not satisfactory for the purpose of enabling the crew of a sunken or disabled submarine to escape. The apparatus (see photographs, inclosure Q) consists of a self-contained

oxygen breathing apparatus with air purifier and of a life belt of cork. The whole outfit can be put on quickly and is in the shape of a vest, fastened in front by means of buckles. The breathing apparatus proper consists of the steel bottle containing about 60 liters of free oxygen, the compressed potash cartridge (for absorbing the exhaled carbonic-acid gas), the breathing bag carried on the back of the wearer, the mouth-breathing device with nose clamp, and the requisite connection tubes. The oxygen content of the cylinder allows about 30 minutes' use, varying according to the requirements of the wearer. It is designed as a rescue apparatus and not for working purposes. The apparatus normally has positive buoyancy. To enable it to be used at more than the maximum safe oxygen pressures, a cylinder containing compressed air only is attached.

103. The objectionable features of the apparatus are:

(*a*) The regulation of the mixing of oxygen and air is left to the operator while under water. Under stress of excitement, incident to the necessity of escape from a sunken submarine, this feature constitutes a great danger.

(*b*) The capacity of the cylinders is too limited to permit the substitution of compressed atmospheric air for compressed oxygen.

(*c*) There is no protection for the eyes and all the details of escape would have to be accomplished without the operator being able to see.

(*d*) The life of the operator depends upon the correct adjustment of a nose clamp. During the excitement of an emergency this adjustment could easily be improperly made. The inhalation of water would cause instant and disastrous results.

(*e*) The successful operation of the apparatus requires a degree of expertness and knowledge of the technique of diving not found among all the members of the crew of a submarine.

(*f*) The capacity of the apparatus is too limited for the conditions to be anticipated in submarine escape.

(*g*) The use of the apparatus in deep water is dangerous to any but expert operators.

104. The conclusions reached as a result of the tests with the Draeger escape apparatus are that a satisfactory escape apparatus must fulfill the following conditions:

(*a*) The apparatus must be simple and practical for use in the maximum depths of water in which escape from submarines may become necessary.

(*b*) Protection of the eyes, nose, and mouth from contact with water must be provided.

(*c*) Provisions for the control of buoyancy are necessary.

(*d*) It must be of the least possible dimensions and weight.

(*e*) It should be as flexible as possible and not liable to get out of order.

(*f*) It should be of not less than one hour capacity.

(*g*) The arrangement must be such that a man can put the apparatus on without assistance.

(*h*) The dangers of deficiency of oxygen and oxygen poisoning must be eliminated.

(*i*) The apparatus must be fitted with a life preserver that will maintain the wearer afloat for an indefinite time after the surface is reached.

(*j*) The capacity and construction of the apparatus must be such that in operation the ascent to the surface from deep water can be accomplished according to the rules applicable to deep diving.

(*k*) The arrangement of the head protection must permit the operator to see objects outside the apparatus.

105. A study of various types of submarine escape apparatus leads to the conclusion that the Hall-Rees submarine escape apparatus, in use in the British and other foreign navies, is the most efficient one now on the market. With certain improvements this apparatus will most likely solve the problem of submarine escape.

106. Instructions have been received to test a submarine escape apparatus to be furnished by Siebe, Gorman & Co., but up to the present moment (Aug. 25, 1914) it has not been received. It is understood that the Siebe, Gorman & Co.'s apparatus is an improvement over the Hall-Rees type of escape apparatus and is suitable for use in deep water. If this is true, it is considerably in advance over other existing types of self-contained diving apparatus. It is interesting to note that the difficulties met with in providing a suitable submarine escape apparatus have been in connection with overcoming the dangers of oxygen and carbonic-acid gas poisoning and in guarding against a deficiency of oxygen. (See Appendix 1 for report.)

107. *Present methods of diving.*—The present method of diving as taught and practiced in the Navy is what is known as the slow or uniform decompression method. No specific rules or regulations are laid down for the guidance of naval divers other than those found in the diving manual. The diving manual is antiquated, lacking in useful information, and contains statements known to be incorrect. The existing general lack of information in regard to the subject and technique of diving is responsible for the lack of efficiency of naval divers, the dissatisfaction with the apparatus, and the antiquated and sometimes dangerous methods employed. The physics and physiology of diving are but little understood. The same mistakes are made and the same troubles are now experienced that were the rule 25 years ago.

108. The maximum depths which naval diver's can usually dive to successfully is about 60 or 70 feet. In some few exceptional cases divers have been to 90 and 100 feet. At these depths they are unable to perform any amount of work. The fact that they do occasionally dive so deep is marvelous when it is taken into consideration that the requirements of air supply and deep diving are practically unknown. Another detriment to the divers is an improper method of communication. It is the custom to use very few signals and to transmit them by pulling on their lines, air signals being usually sent by the hose and working signals by the life line. No case is known where real efficient telephonic communication has been established or that would meet all requirements.

109. Naval divers are poorly trained. At the diving schools the individual pupil is fortunate if he is able to go under water more than a half dozen times during his course of instruction. The details of contruction and use of the apparatus is explained to them in an indifferent and incapable manner, and often the advice of the instructors is erroneous. Newly qualified divers arriving on board ships are, as a general rule, incompetent and unable to assume the responsibility of taking charge of a diving operation. The majority of men do no diving that amounts to anything after leaving the school. The reason for this is, that after one or two trials under service conditions they find the conditions severe and rather than face the disgrace of failure they refuse to dive any more, or attribute their inability to do the work to some physical imperfection. Others are simply frightened by the conditions found, and some never have an apportunity to try their ability. A small proportion of the men passing through the diving classes become really good divers and do remarkably fine work at moderate depths, even though they have always to work under many disadvantages.

110. Officers as a rule do not pay much attention to diving except in special cases when some special duty brings them in contact with diving operations. Accidents to divers are common and fatal cases are not unknown. Nearly every experienced diver can recall some narrow escape. The extra compensation paid to diver for work under water is inadequate ($1.20 an hour). This rate applies whether the work is successful or not. No distinction is made between dangerous and hazardous or light work; whether the conditions are good or bad; whether the water is of a freezing or comfortable temperature; whether the time is day or night; or whether the diver recovers valuable Government property or merely makes a casual observation. As an instance: A diver may spend several hours cleaning a propeller. He is in shallow water, in good light, in a comfortable position, and has plenty of air. He earns several dollars and has an easy time of it. Another man, less fortunate, has

to descend in deep water and recover an anchor or a torpedo lying on a muddy bottom in a tideway. The weather is bad and the water cold. If he accomplishes his task in record time, he gets very little for the risk he runs and the physical strain of difficult and dangerous duty. During my own service as a diver I have recovered many thousands of dollars worth of Government property, such as torpedoes, anchors, anchor cables, small arms, pieces of machinery, etc., and have accomplished much repair work, inspections, etc., and, as I remember, the total extra compensation I have received amounts to less than $20. On one occasion I saved the necessity of placing the U. S. S. *Lawrence* in dry dock, for which work I received a check for 80 cents. On still another occasion I successfully secured and caulked a wooden cofferdam over the mouth of the starboard after-submerged torpedo tube on board the U. S. S. *Georgia*, at Provincetown, Mass., and assisted in returning the inner tube to battery. The inner tube had been run out during torpedo practice and a broken gear wheel caused it to remain fixed in the extreme outboard position. The large gate valve could not be closed and the spoon on the end of the inner tube projected outside the hull of the vessel. The cofferdam kept the water out and permitted disassembling the torpedo tube and correcting the trouble, thus saving the necessity of proceeding to a navy yard and placing the ship in dry dock. For this work my services were gratis (see paragraph 54). These personal experiences are mentioned merely to invite attention to the advisability of offering special inducements to naval divers that will cause them to take an interest and become proficient in their work. A diver at his work is not in an ordinary condition of life. He has to undergo an ordeal that requires mental and physical strain. His duty is usually important and requires technical training. The rates of compensation can be arranged so that, at a small increase in cost, a much higher degree of skill and efficiency among divers can be obtained.

111. *The dangers met with in diving and the methods of avoiding or overcoming them.*—The principal cause of the hardships and distress commonly experienced by naval divers under present conditions is due to the practice of providing an inadequate air supply for the depths attempted. The requirements of a diver's air supply are explained in paragraphs (23) to (35), inclusive. When the requirements of air supply are learned and applied in practice the working capacity of the diver will be found to be practically unlimited and also that he can descend to very great depths without difficulty. When deep diving is attempted, however, unless the ascent be properly managed, a new and serious danger arises due to the formation of bubbles of nitrogen gas in the fluids and tissues of the body. The condition is known as "caisson disease" or "compressed-air

illness." Mild cases as evidenced by pains in the joints are generally referred to as the "bends" by compressed-air workers and the more serious ones as "diver's palsy." Other dangers to be reckoned with in diving operations are those in connection with "falls under water," "blowing up," "getting fouled," "suffocation," "drowning," "pressure on the ears," and "phonetic troubles with the language."

112. "Caisson disease": The report of Passed Asst. Surg. G. R. W. French, United States Navy, covers this subject, as well as other physiological questions relating to diving operations in detail, hence only a brief reference is attempted here, sufficient to enable an understanding of the practical changes found necessary to be made in the methods of diving to avoid an occurrence of any of the various known symptoms of compressed-air illness. (See Appendix 3.)

113. While it is true that the troubles previously experienced by divers in descending have been erroneously attributed to pressure, it is also true that their troubles after reaching the surface are attributable to conditions resulting from subjection to excessive air pressure. The greater the exposure the more serious the risk, and in extreme cases a diver returning from deep water may develop symptoms which may end in death within a few minutes or hours.

114. When a gas is brought into contact with a liquid, the latter takes up the gas in simple solution (apart from any chemical affinity) until a state of saturation is reached. The amount thus taken up depends upon the coefficient of solubility of the gas in the liquid and the temperature of the liquid and varies directly with the pressure of the gas& The blood passes passing through the lungs is ~~practically~~ in contact with the air breathed and therefore takes up, when a man is in ~~compressed air, an~~ increased proportion of nitrogen in simple solution in accordance with Dalton's law.

115. The increased proportion of nitrogen taken up by the blood ~~in compressed~~ air passes to the various semiliquid tissues, which gradually also become saturated, since nitrogen, unlike oxygen, does not disappear by passing into chemical combination. The whole body thus gradually becomes saturated with nitrogen at the pressure which this gas exerts in the compressed air. That the blood does actually become saturated in this way has been definitely proven by various European observers.

116. If the excess of air pressure is rapidly removed, as occurs when a diver comes quickly to the surface, it is clear that the blood in the tissues will for a time be in a condition of supersaturation for the diminished pressure. In consequence the nitrogen will tend to liberate itself in the form of bubbles just as CO_2 is liberated in bubbles when the cork of a bottle of soda water is removed. It does not follow, however, that any actual, or at any rate any rapid, for-

mation of bubbles will occur, particularly in the case of an albuminous liquid like the blood. In practice there seems to be no danger in sudden decompression unless the absolute pressure is reduced to less than half what it was, and the lowest pressure by rapid decompression from which a fatal accident has been recorded is 23 pounds per square inch, or 2.5 atmospheres of pressure, corresponding to 53 feet of sea water.

117. The higher the pressure and the longer within certain limits the exposure to it the more absolute the certainty of death becomes. How very great the risks of rapid decompression are is abundantly shown by records of accidents to divers as set out in the books and papers quoted in paragraph 10. There is much evidence to show that in different individuals the risk arising from decompression at a given rate, after exposure for the same time to the same pressure, varies considerably. In the case of divers variability to susceptibility seems to exist, some men appearing to be immune from symptoms under conditions where other men are affected. The fact that one diver has repeatedly escaped serious decompression symptoms under certain conditions does not prove that other men would be equally immune. A considerable margin of safety is desirable beyond what would seem to have proved safe in individual cases. As susceptibility to decompression symptoms has been definitely proved to increase after middle age is reached, men over 45 years should not be permitted to undertake deep diving. The conclusions of Dr. A. E. Boycott, and Lieut. G. C. C. Damant, R. N., inspector of diving, are that really fat men should never be allowed to work in compressed air and plump men should not be permitted to dive to more than about 10 fathoms, and at this depth the time of their exposure should be curtailed. If deep diving is to be undertaken, skinny men should be selected. Middle-aged men have a lower rate of respiratory exchange than young men; if fatness is not the explanation of this, they are at a double disadvantage, and the two factors must be multiplied rather than added together.

118. *Methods of avoiding the danger of caisson disease.*—There are two methods of securing safety in decompression. One is to limit the time during which the diver is exposed to high pressure and the other is to bring him up very slowly. In very deep diving the first method is chiefly used for the reason that heretofore the diver could not stay below on account of the distress caused by the CO_2 pressure. When the period of exposure to high pressure is limited to a short time, the blood and tissues have not time to become saturated with nitrogen at the high pressure and the risk of bubbles being formed on decompression is thus obviated. Experience in caissons proves that even after an hour the tissues are not completely saturated,

since the risks on decompression are very much less than after two or more hours' time.

119. The second method has been for long employed by divers doing serious work in very deep water, although they usually also confine their stay on the bottom to a short period, such as 10 or 20 minutes. Divers frequently come up in three or four minutes from depths of 15 fathoms without ill effects, although accidents occasionally happen. The comparatively short time under high pressure lessens the chance of accident, and if this time be sufficiently reduced a diver can safely ascend from a depth of 25 fathoms or more within one minute.

120. *Processes occurring in the body.*—Absence of a careful consideration of these processes has led to many mistakes in the practice of diving hitherto adopted. The blood passing through the lungs becomes instantly saturated or desaturated to the exact extent of the pressure of the nitrogen in the air breathed. During compression, as a diver goes down, the blood leaving his lungs will always be charged with dissolved nitrogen in proportion to the absolute pressure of the air he is breathing. The same will hold for decompression as he comes up, and since the arterial blood leaves the arteries within half a minute at most, and bubbles scarcely seem to form within this time, there will be no risk of bubbles actually forming in the arterial blood during decompression, except when it is almost instantaneous. With very rapid decompression, however, small bubbles which have passed through the capillaries of the lungs may easily increase in size in the arteries. ~~If the nitrogen only~~ in the blood had to be taken into consideration, the problems of safe decompression would easily be solved. The actual conditions are, however, much more complex, since there must be considered not only the excess of nitrogen in the blood but also the excess in the tissues. Just as in the lungs, the nitrogen pressure of the blood becomes by diffusion equal to that of the body, a similar equalization process takes place by diffusion through the thin walls of the capillaries; and the veinous blood leaving the capillary vessels of the tissues will consequently have about the same nitrogen pressure as the tissues themselves. Since the mass of the whole body is about 20 times the mass of the blood, and its capacity for taking up nitrogen ~~in solution~~ is probably nearly as great as that of the blood, [illegible] it will take a considerable time to saturate the tissues of the body with nitrogen in compressed air or desaturate them on decompression. The process will also be a lingering one, since the blood will at each round of the circulation yield less and less nitrogen to the tissues, or vice versa.

121. In the process of desaturation during and after decompression, if the pressure were lowered suddenly and no bubbles were liberated,

desaturation of the tissues and veinous blood would occur at the same rate as saturation. Experience shows clearly that even with rapid decompression there is practically no risk of symptoms from bubbles being liberated unless the air pressure exceeds about 20 pounds, and that even with 25 pounds symptoms are not common, though with higher pressures the liability very rapidly increases and becomes very marked when a pressure of 30 pounds is exceeded. It is evident that if the air pressure is lowered gradually and evenly, the nitrogen pressure in the tissues must lag further and further behind the fall in air pressure however slow the decompression may be. The danger of bubble formation depends upon the difference in relative pressure, and not absolute pressure, between the air and the nitrogen dissolved in the tissues. The difference must be in the proportion of more than 2 to 1 before bubbles form "large gas" appreciably, and decompression can be safely proceeded with if the difference is not more than in the proportion of about 2 to 1.

122. *Disadvantages of uniform method of decompression.*—The practical deductions from the foregoing conclusions are of considerable importance, since in all probability safe decompression can be conducted with considerably less expenditure of time than if it is carried out by uniform diminution of the air pressure, as has been hitherto the common practice. As previously stated, the absolute difference between the air pressure and the nitrogen pressure in the tissues necessarily goes on increasing during uniform decompression and is greatest at the end of the decompression, therefore uniform decompression is without the slightest doubt an unsuitable procedure. When it is taken into consideration that it is the relative and not the absolute difference in nitrogen pressure that matters, the unsuitability of uniform decompression becomes far more evident. It is evident that with uniform decompression a part of the time spent in the process is lost, for during the greater part of the time spent in uniform decompression the difference in pressure between the nitrogen in the tissues and that in the air is much less than it might safely be made, and, as a consequence, the nitrogen is given off from the lungs much more slowly than would be safely possible.

123. *The stage decompression method.*—If the absolute pressure were reduced without delay to about half, much time would be saved without overstepping the limits of safety. The rest of the decompression could be carried out slowly, and with gradually increasing slowness as atmospheric pressure is approached; the rate being so calculated that the difference in relative gas pressure between the air and any part of the tissues should never exceed a safe limit, such, for instance, as 2 to 1. A calculation will show that it would take, at the best, about three hours to decompress safely a man whose body was saturated

at a pressure of 30 fathoms or 80 pounds. With uniform decompression the time needed would be very much longer. Such long periods of decompression as an hour or more are not practicable under ordinary conditions of diving. It is thus essential to limit the period of stay of a diver on the bottom in deep water. To give a diver at the same time a sufficient time to carry out serious work it is also, however, necessary to take proper precautions in decompression.

124. In deep diving certain practical points are of much importance. In the first place, the diver should get down to the bottom as quickly as the pressure on the drums of his ears, or the pressure of his dress round him, will permit. While he is descending he is taking up nitrogen all the way, and, roughly speaking, he will absorb during his descent, if it is at a uniform rate, half as much nitrogen as he would absorb during an equal time on the bottom. Hence time spent in descending is all to the bad. The advice usually given to divers to descend slowly into deep water is very unsound (unless, indeed, the air supply from the pumps is so bad that the diver does not know whether he can get down at all). The present Service Manual for Divers recommends, for instance, a rate of descent of a fathom a minute. At this rate a diver would take 35 minutes to get down 35 fathoms; and before he touched bottom he would already be most dangerously saturated with nitrogen. A good diver is not troubled by his ears, and if he has a plentiful supply of air from the moment of submersion his dress and helmet will never press upon him owing to compression of the air within the helmet as he goes down. During the deep-diving tests all the divers were easily able to descend at the rate of 100 feet per minute and faster. The actual record was in the case of Chief Gunner's Mate S. J. Drellishak, who subjected himself to 90 pounds excess pressure (201 feet) in 40 seconds. Such speed in descending is, however, only possible when the air supply is adequate. An inadequate air supply will compel a diver to stop short owing to pressure of the dress and the difficulty in breathing.

125. Another equally important point is to get up out of the very high pressure as quickly as is safely possible. The reasons that a diver can come up quickly to half the absolute pressure with safety have already been stated. At 12 fathoms the absolute pressure is half that at 30 fathoms; and at 12 fathoms a diver is already out of any formidable pressure. Suppose that, instead of coming straight up within three or four minutes to 12 fathoms, a diver who has been down for a few minutes at 30 fathoms ascends at a uniform rate of 12 fathoms in 15 minutes. It will thus take him 15 minutes to reach 18 fathoms. This is not merely a waste of time, but exposes him to additional risk, about equivalent to an extra 15 minutes at 24 fathoms or 12 minutes at 30 fathoms, during which the tissues in at any rate

most parts of his body will be absorbing nitrogen. Thus, supposing he comes up and goes down at a uniform rate, taking about 40 minutes each way, and spending 10 minutes on the bottom, the total period of exposure will be about equivalent to 20 minutes at 30 fathoms for going down, 10 minutes actually spent at 30 fathoms, and say, 12 minutes at 30 fathoms in coming up—42 minutes in all. He will be fortunate if he escapes an attack of paralysis, or asphyxia, or "bends" on coming to the surface, which he will reach in 15 minutes from 12 fathoms, and 5 minutes from 4 fathoms, the rate of ascent at the end being most dangerously fast.

126. In the case of a diver whose stay on the bottom in deep water has been very short, the reasons for hastening not merely the descent, but all the ascent except the last part, are especially cogent. His only tissues which will have become saturated will be those which saturate and desaturate rapidly; no part of his body will be fully saturated; and the parts which saturate very slowly will not have taken up sufficient nitrogen to be capable of causing any trouble at all on decompression. He can thus be brought safely at a rapid rate to less than half the absolute pressure; and even the remaining stages can be greatly hastened. Delay at any depth beyond 8 fathoms may only increase his risk; and delay in the first half of his ascent will certainly do so.

127. The following two tables, constructed by the British Admiralty deep-water diving committee, showing the stoppages required after dives to various depths and with various periods of stay on the bottom, were carefully tried out and found to be safe and practical. The first table refers to ordinary limits of stay on the bottom, the limits being such that a diver can always return to surface safely within about half an hour at most, and might return by stages much more rapidly without serious risk. The second table is for longer periods on the bottom. A diver might get foul of something on the bottom, and thus be unable to return within the limit of time specified in the first table; or for some other reason it might be necessary for him to remain for an extra long time. The table provides for enforced stays of any duration, but as the time needed to reach surface without risk of even slight symptoms, such as "bends," is very long, and the risks from exhaustion and cold during the process have to be considered, the stoppages during the ascent after the longest exposures are only sufficiently long to prevent any serious symptom of caisson disease from occurring. Both human experience and the experiments on goats show that with long exposures to pressure a rate of decompression can be selected which is sufficient to prevent any serious symptom, but not sufficient to prevent "bends" occurring. The precaution of exercising the limbs during the stoppages will, however, probably

reduce the risk of bends. The experience of Drs. Hill and Greenwood points distinctly in this direction. If the diver can not exercise his limbs, or if he is of heavy build owing to excess of fat in his body, the stoppages should be fully a third longer if possible. The British Admiralty deep-diving experiments disclosed the very remarkable fact that nitrogen is about six times as soluble in fat as in an equal weight of blood at the body temperature. It follows that a fat man will take longer to saturate with nitrogen in compressed air and longer to desaturate during decompression. See paragraph (117).

Decompression Table No. 1.—*Ordinary time limits in deep water and stoppages during ascent, in accordance with Prof. Haldane's recommendations and latest British Admiralty practice.*

Depth.	Time under water, i. e., from surface to beginning of ascent.	Stoppages at different depths.						Total time for ascent.
		60 feet.	50 feet.	40 feet.	30 feet.	20 feet.	10 feet.	
Feet.								*Minutes.*
0- 36	No limit							0-1
36- 42	Up to 3 hours							1-1½
	Over 3 hours						5	6
42- 48	Up to 1 hour							1½
	1 to 3 hours						5	6½
	Over 3 hours						10	11½
48- 54	Up to ½ hour							2
	½ to 1½ hours						5	7
	1½ to 3 hours						10	12
	Over 3 hours						20	22
54- 60	Up to 20 minutes							2
	20 minutes to ¾ hour						5	7
	¾ to 1½ hours						10	12
	1½ to 3 hours					5	15	22
	Over 3 hours					10	20	32
60- 66	Up to 15 minutes							2
	¼ to ½ hour						5	7
	½ to 1 hour					3	10	15
	1 to 2 hours					5	15	22
	2 to 3 hours					10	20	32
66- 72	Up to 15 minutes						2	4
	¼ to ½ hour					3	5	10
	½ to 1 hour					5	12	19
	1 to 2 hours					10	20	32
72- 78	Up to 20 minutes						5	7
	20 to 45 minutes					5	15	22
	¾ to 1½ hours					10	20	32
78- 84	Up to 20 minutes						5	7
	20 to 45 minutes					5	15	22
	¾ to 1¼ hours					10	20	32
84- 90	Up to 20 minutes					3	5	10
	20 to 40 minutes					5	15	22
	40 to 60 minutes				3	10	15	30
90- 96	Up to 20 minutes					3	5	11
	20 to 35 minutes					5	15	22
	35 to 55 minutes				5	10	15	32
96-108	Up to 15 minutes					3	5	11
	15 to 30 minutes				3	7	10	23
	30 to 40 minutes				5	10	15	33
108-120	Up to 15 minutes				2	3	8	15
	15 to 25 minutes				5	5	10	23
	25 to 35 minutes				5	10	15	33
120-132	Up to 15 minutes				2	5	7	17
	15 to 30 minutes				5	10	15	33
132-144	Up to 12 minutes				3	5	5	16
	12 to 25 minutes			2	5	10	12	32
144-156	Up to 10 minutes				3	5	5	16
	10 to 20 minutes		2	3	5	8	10	31
156-168	Up to 10 minutes			2	3	5	5	18
	10 to 16 minutes		2	3	5	7	10	30
168-180	Up to 9 minutes			2	3	5	5	18
	9 to 14 minutes		2	3	5	7	10	30
180-192	Up to 13 minutes		2	3	5	7	10	30
192-204	Up to 12 minutes	2	2	3	5	7	10	32

Decompression Table No. 2.—*Stoppages during ascent after exceeding the ordinary limits of time on the bottom, in accordance with British Admiralty practice.*

Depth.	Time from leaving surface to beginning of ascent.	Stoppages at different depths (in minutes).								Total time for ascent.
		80 feet.	70 feet.	60 feet.	50 feet.	40 feet.	30 feet.	20 feet.	10 feet.	
Feet.										*Minutes.*
66	Over 3 hours							10	30	42
72	2 to 3 hours							10	30	42
	Over 3 hours							20	30	52
78	1½ to 2½ hours							20	30	52
	Over 2½ hours							30	30	62
84	1¼ to 2 hours							15	30	47
	2 to 3 hours						5	30	30	67
	Over 3 hours						10	30	35	77
90	1 to 1½ hours						5	15	25	47
	1½ to 2½ hours						5	30	30	67
	Over 2½ hours						20	35	35	92
96	55 minutes to 1½ hours						5	15	30	52
	1½ to 2½ hours						10	30	35	77
	Over 2½ hours						30	30	35	102
108	40 minutes to 1 hour						10	15	20	48
	1 to 2 hours					5	15	25	35	83
	Over 2 hours					15	30	35	40	122
120	35 minutes to 1 hour					5	10	15	25	57
	1 to 2 hours					10	20	30	35	97
	Over 2 hours					30	35	35	40	142
132	½ to ¾ hour					5	10	15	20	53
	¾ to 1½ hours				5	10	20	30	30	98
	Over 1½ hours				15	30	35	40	40	163
144	25 minutes to ¾ hour				3	5	10	15	25	61
	¾ to 1½ hours				10	10	20	30	35	108
	Over 1½ hours				30	30	35	40	40	178
156	20 to 35 minutes				3	5	10	20	20	61
	35 minutes to 1 hour				7	10	15	30	30	95
	Over 1 hour			20	25	30	35	40	40	193
168	16 to 30 minutes				3	5	10	15	20	56
	30 minutes to 1 hour			3	10	10	15	30	30	101
	Over 1 hour		5	25	25	30	35	40	40	203
180	14 to 20 minutes				3	3	7	10	15	41
	20 to 30 minutes			2	2	3	10	15	25	60
	30 minutes to 1 hour		3	3	7	10	20	30	25	111
	Over 1 hour		15	25	30	30	35	40	40	218
192	13 to 20 minutes				3	3	7	15	15	46
	20 to 30 minutes			3	3	5	10	15	25	64
	30 minutes to 1 hour		3	5	10	12	20	30	35	118
	Over 1 hour	5	20	25	30	30	35	40	40	228
204	12 to 20 minutes			3	3	5	7	10	20	51
	20 to 30 minutes		3	3	3	5	10	20	30	67
	30 minutes to 1 hour	3	3	5	10	15	20	30	35	124
	Over 1 hour	15	20	25	30	30	35	40	40	238

130. As illustrating the risks involved in the current method of descent and ascent, even when the time on the bottom does not exceed 30 minutes, at a depth of only 20 fathoms, the following is quoted from the report of British Admiralty deep-water diving committee:

> We may relate the following recently reported experience of five divers of H. M. S. *Diana* during operations for the recovery of an anchor and three shackles of cable in about 20 fathoms of water at Lagos. The work was carefully superintended, and the descent and ascent were carried out in close accordance with the recommendations of the Diving Manual. The times were noted, and were as follows:

	Going down.	Coming up.	On bottom.
21.2.07 Diver A	29	34	30
B	34	39	22
C	32	38	20
D	33	37	30
E	38	34	30
22.2.07 Diver A	30	37	30
B	25	35	30
E	30	36	30
C	29	36	25

Of the five divers, A suffered after his second descent from nausea and vomiting, which, however, soon passed off, and may have been due only to the excessive pressure of CO_2 in the air of the helmet from the inadequate air supply. Diver D shortly after his ascent developed symptoms (faintness, dizziness, etc.) pointing distinctly to serious blockage of the circulation by bubbles in the heart. Diver E developed similar symptoms after his second descent. Both were on the sick list for five days, but completely recovered. It will be noted that the symptoms were not the "bends" which are so common among workers in caissons, tunnels, etc., but of a far more threatening character. In framing the appended tables we have kept clearly in view the fact that in the case of divers with comparatively short exposures to pressure the symptoms to be guarded against are much more serious than "bends."

131. In the tables, paragraphs 128 and 129, quoting further from the Admiralty report:

The rates of decompression are all calculated as safe for the corresponding maximum pressures and maximum periods of exposure. For instance, at the greatest depths the decompression rate for "over one hour" is calculated as safe for a stay of any duration, so as to meet the case of a diver being badly fouled that he can not get free until the tide turns.

A diver has often to descend twice or oftener at short intervals. It is evident that at the beginning of the second descent the more slowly desaturating parts of the body will not have had time to lose their excess of nitrogen, and that consequently they will be more highly saturated at the end of the second stay on the bottom than would otherwise have been the case. To meet the increased risk in decompression owing to this circumstance, it is desirable, in calculating the proper rate of decompression, to add together the two periods of stay on the bottom and adopt the corresponding rate of decompression. For the first half of the stoppages this is not necessary, but for the second half, including, of course, the longer stoppages required to meet the case of the more slowly desaturated parts, the rule should be carried out. Reference has already been made to the increasing danger experienced by pearl divers after successive dives without any precautions in decompression. This danger does not mount up to the same extent if stage decompression be used, but nevertheless exists.

As the interval of time between two successive dives increases, the extra danger in decompression diminishes. With an hour's interval the extra precautions in decompression might be halved, and with two hours' interval they might be entirely omitted.

In general, the precautions recommended in the tables are greatly in excess of those which have hitherto been commonly employed in either diving, work in caissons, tunnels, etc. We have endeavored to leave a clear margin beyond anything which either human experience or experiments on animals, or calculation, has shown to be risky; and fortunately it has been possible to do this with a clear saving of the time spent under water (with ordinary limits of working time) by divers at all depths, and a great increase in working efficiency and comfort. We have every reason to believe that if these precautions for divers, and the corresponding ones for other workers in compressed air, are carried out, the risks to life and health from caisson disease will practically disappear.

132. During the tests and experiments covered by this report the exact limits set forth in the Admiralty decompression tables were deviated from to find out whether or not in practice the periods of time of decompression from various depths could be abbreviated. In all cases where the period of exposure had been protracted at high air pressures a shortening of the time of decompression as shown in

the tables resulted in the appearance of symptoms of the bends, thus proving conclusively that the tables are practical and none too long.

133. It is with difficulty that divers can be made to see the necessity of and apply carefully the principles of stage decompression. The long wait in the water becomes irksome and as symptoms seldom, if ever, occur during actual decompression, the tendency is to doubt the necessity for the precautions being taken and to hasten the ascent. During the deep diving tests the divers were kept under medical observation for a specified length of time after decompression, and provisions were made for recompression in case of necessity. It came to my knowledge that the divers would actually conceal slight attacks of the bends rather than take the trouble to be recompressed when they knew from experience that recompression would afford instant relief. In my own case, on one occasion, I was suffering from slight but unmistakable symptoms and neglected or rather objected to recompression, contrary to the advice of the attending surgeon. I proceeded to my home and the conditions became steadily worse. At the end of three hours after decompression I was in a bad way and suffering excruciating pain. I was also nauseated, faint, and prostrated. Under the care of Dr. French I gradually recovered and at the end of five hours after decompression was myself again, excepting for a general discoloration and soreness of the skin over the main portions of the body. Dr. French, himself, suffered slight attacks of the bends on more than one occasion.

134. *Blowing up.*—Blowing up of a diver (sudden rise to the surface) is apt to be followed by serious consequences and is to be guarded against as a grave danger. A diver can blow himself up in shallow water, perhaps up to 7 fathoms, without any danger from caisson disease, but in doing so he runs the risk of getting fouled or of striking some object at the surface. Blowing up from deep water is decidedly dangerous. It is apt to occur from accident when a diver is crawling with his head down or from a sudden increase in air supply. With head down the water pressure on the helmet is increased and, consequently, the escape of air is checked. The tendency, therefore, is for the air to accumulate in the back part of the dress and, if that continues, the diver soon finds himself helpless and on his way to the surface with a dress so distended that he can not move his arms. He may even be capsized with head down if much air gets into the legs of the trousers. As he leaves the bottom air expands under the diminished pressure and his movement to the surface is accelerated. If he strikes anything, as the bottom of a ship or boat, the force of the contact may easily rupture the helmet or some other part of the apparatus. The air within the dress would then exhaust, the dress would collapse, and the diver would be sub-

jected to the additional danger of a fall back to the bottom. If blown up, therefore, from any depth, the slack of his lines should be taken in quickly so as to prevent a fall. His dress should then be relieved of the excess volume of air by holding the helmet up and opening the escape valve. There is little danger of the dress exploding from the sudden increase of the volume of air due to diminished pressure, if the diving gloves are not securely attached, as the excess of air will escape at the cuffs. When the excess air has been relieved the diver should be sent down again with the least delay and be decompressed in accordance with the tables. The plan of lacing up the legs of the diving dress prevents their distension with air, the liability of blowing up, and capsizing of the diver. The use of the improved diving gloves will also prevent the suit from exploding as the result of blowing up from deep water, in cases where diving gloves are worn. An open ended sleeve is a great protection to the diver as the elastic cuff will act as a safety valve and prevent overinflation from any cause. To exhaust excess air in this manner a diver has only to elevate his arm so that the cuff is about the level of the helmet or a little higher. The exhaust will follow the line of least resistance and equilibrium can be maintained in this manner. The reason for sending the diver down again immediately after his having been blown up is that from this cause, considering the object of the tables, he arrives at the surface in a condition most favorable to the development of caisson disease, and that his danger is in proportion to the time he has been exposed to high pressure.

135. *Falls under water.*—Air can not be supplied to the inside of a dress by the pumps at more than a certain rate, hence, if for any reason a diver changes his depth at a greater rate than that at which the pumps can supply him with the proper volume of air he may be subjected to a very dangerous "squeeze" from the water. For instance, should a diver fall 5 fathoms. At this depth the absolute pressure is twice as much as it is close to the surface, so by the descent the volume of air in his dress is diminished by half. He has an additional pressure of nearly 15 pounds suddenly applied to every square inch of his body, or about 2,000 pounds for every foot. As the helmet is rigid, his body will be crushed into it with overwhelming force. He may be killed, he certainly will be severely injured, and there will be bleeding from the lungs, mouth, nose, etc. If, however, the diver is at 165 feet (27.5 fathoms) and falls 5 fathoms, pressure has only increased in the proportion of 7 to 6, and the volume of air within his dress has only diminished by less than one-seventh of its volume, so that the effect will be proportionately less. From this it follows that the deeper a diver is, the less serious is a fall. The "squeeze" is also practicable during the management of the ascent. The diver is dependent upon signals for knowledge of when to stop during stages of decompression and when to leave

one stage for another. The depth of the diver is deduced from the pressure shown by the gauge, but so long as the pump is working the gauge pressure exceeds the water pressure. Therefore, as the diver is ascending at the rate of about 1 foot per second, there is danger that he will come up too high before he is stopped. To avoid that situation it is customary to stop a diver when the gauge appears to indicate a depth of 4 or 5 fathoms below the first stopping place. The pump is then stopped a little time, there being quite sufficient air in the dress to make that practicable, the gauge being tapped to make it more lively and the true water pressure ascertained. At the same time the diver is signaled to come up slowly, and then stopped at the right depth, when the pump is immediately restarted. If in this procedure the diver has been allowed to get above the stopping place he is sent back to the right depth, but unless the pump is started before he begins the descent there is liability of a "squeeze."

136. *The danger of fouling.*—One of the most serious accidents that can happen to a diver under water is that of getting fouled, especially if the water is deep. Unless he can clear himself, or be cleared, in a reasonable length of time he may succumb from either one or a combination of the following causes: Exhaustion, effects of cold, oxygen poisoning, suffocation, or drowning. More fatal accidents are probably recorded from this cause than from any other. Probably the most widely known case of this kind was that of the fatal accident to a diver, in New York State, employed in repair work around the control valve of a pipe leading from a large reservoir. The diver was attempting to guide a large metal ball into the mouth of the pipe when he slipped, lost his balance, and the suction drew one of his legs into the pipe and at the same time the ball rolled into its seat and held him fast for several days. Every effort was made by divers and others to release him but without avail until, as the last resort, the remaining valves controlling the city's water supply were closed and the pressure in the pipe was equalized with that of the water in the reservoir. The diver continued to signal for assistance for nearly three days but died from nervous shock and exhaustion before his body was released. A diver, in the British navy, recently suffered a fatal accident owing to an anchor buoy fouling his lines while the ship under which he was working swung to the tide. An American diver working at the bottom of a Connecticut river became stuck in the mud. In the attempt to clear him his air hose parted and he died from suffocation. Many other cases on record could be cited, but these three serve as a sufficient illustration. In cases of fouling in deep water, in addition to other troubles, the men on the pumps may become tired from their exertions and be unable to keep up the requisite air supply, in which case the diver would suffer from the effects of CO_2; also, he acquires,

during his enforced stay in deep water, a dangerous saturation of nitrogen. In this connection it is interesting to note the experience of Gunner A. Y. Catto, R. N., during the British Admiralty deep-diving experiments. Mr. Catto descended in 30 fathoms of water, off Loch Riddon, and "attempted to shackle a hawser on to a sinker. He found the sinker without difficulty, and then, having tied his distance line to it, went back to the hawser. He found this in bights, and he seems to have got within the coils, and in trying to find the end of the wire to have fouled his life line. When called up he could not get away, and it was 20 minutes before he could clear himself. In all, he was down 28 minutes and 45 seconds in 30 fathoms of water. The rate of the pumps could not be kept up above 24 revolutions per minute, and the supply of air was not adequate to his exertions to free himself, so he was almost overcome by the excess of CO_2. On account of his long exposure during heavy work, great care was taken in decompressing him, 1 hour and 30 minutes being allowed. There were no ill effects."

137. The great danger of diving around wrecks, moorings, mines, etc., is that the diver may get foul, thus anchoring himself to the bottom, and after the tide has begun to run strongly there is not much chance of his clearing himself until the next slack water. To avoid this, diving should not be attempted unless there is enough light on the bottom for the diver to see well all around him. Diving must be stopped directly the tide begins to change and not restarted until the current is setting in a steady direction. The air hose and lines must be seized together and the attendant must not allow his attention to wander. It is absolutely necessary that the telephone be in working order. If the diver finds that he is foul he should think the matter over and try to remember how he got foul before he starts dipping air hose, lines, etc. He should clear himself without hurry; violent exercise will daze him and make matters worse. The distance line is a safe guide and will generally show him the way out of the tangle. He should never let it go if he can help it. If signals can be got through it is usually well to get the attendants to take up the slack of air hose and life line. If the diver starts panting he should take a rest.

138. *Suffocation.*—As already explained, a diver under water may be affected seriously by CO_2 if his air supply is insufficient; and there is no doubt that in the past divers have often been rendered unconscious from this cause. With care in testing the pumps and arranging a proper air supply there should be no fear of such an accident. Its occurrence would be indicated by the diver ceasing to answer signals, perhaps after signaling for more air.

139. It should be remembered that loss of consciousness from CO_2 poisoning is in itself by no means so serious a symptom as loss of consciousness from want of oxygen, and that a diver is very likely to

suffer from the latter condition. On the other hand, if an unconscious diver were drawn rapidly to the surface after a stay of some time in deep water he would run a great risk of caisson disease; and a death clearly proved to be brought about in this way was recently recorded in the Austrian Navy. A diver who has been rendered unconscious by excess of CO_2 ought not, therefore, to be hauled up beyond the first stopping place indicated by the table, according to his depth and duration of stay on the bottom. The diminution of pressure will probably at once relieve him. If he does not now answer signals he should be hauled up, and if he is not breathing, artificial respiration should be applied at once. On his recovery he ought, if possible, to be sent down again.

140. *Drowning.*—There are three cases of drowning in the diving dress in the British Navy—one in which the diver cut his dress in trying to sever his life line to clear himself when foul, the others in which the divers' helmets came off under water. During December, 1913, on board the U. S. S. *Paducah* in Palamos Bay, Cuba, Chief Gunner's Mate W. F. Hill, United States Navy, was drowned while diving to clear the propeller. His life line and air hose became fouled so that he could not signal in time. When his body was brought up life was nearly extinct. The medical officer, assisted by the hospital steward and apprentices and by members of the crew, worked on him for over two hours without success. Hill was diving with a helmet only, and the supposition is that he fell, head down, water entered the helmet, displaced the air, and he was unable to right himself. Such accidents as the helmet working off would have been impossible had the safety catch been down and the weight lanyards rove through the hooks provided for them on the helmet. Cuts in the dress are not dangerous if the diver at once gets into the erect position and comes to the surface without delay, taking all the usual precautions. The treatment of cases of drowning will proceed on the usual principles, artificial respiration being begun at once and continued until a medical officer has been obtained.

141. *Pressure on the ears.*—When descending under water, by the time the diver is down a fathom or two he will probably notice pain in his ears, which may get severe as he gets a little deeper. This is due to the increasing pressure of the air in the helmet on the outside of the ear drums and the closing of the eustachian tubes. If the eustachian tubes are always freely open there will be as much pressure inside the ear drums and consequently no strain upon them and no pain, but in most persons the tubes do not allow the air to pass through them readily and the pressure will not become balanced. To get rid of the pain these must be opened. There are three ways in which a diver may try to accomplish this: One is by pressing the nose against the front of the helmet, closing the mouth and then

making a strong effort of expiration so as to produce temporarily an extra pressure inside the throat and so blow open the tubes; another way is to swallow several times; a third method is by yawning or going through the motions of yawning. A good diver is never troubled with pains in the ears, no matter how rapidly the increase in pressure. Much pain in the ears is a warning that should not be disregarded.

142. *Phonetic troubles with the language.*—Under various air pressures the voice is altered, speech becomes nasal in quality, and has a metallic clang. At very high pressures voices lose their individual character and sound much the same. The resonating effect and so the timbre of the voice is altered by the compressed (less mobile) air within the cavities of the mouth, nose, etc. It is impossible to whistle in air at 2.5 atmospheres excess pressure. There is a sensation of resistance or impediment in the resonating cavities. Speech requires greater effort. Owing to the difficulty of a diver being able to make himself understood over the telephone at very high pressures, an auxiliary means of communication should always be arranged previous to the descent in deep water. Lack of efficient communication is a most serious handicap to a diver.

143. *Further results of tests and experiments.*—The efficiency of the Navy diving apparatus, the improvements necessary to be made in order to bring it up to the requirements of the best practice, the requirements of a diver's air supply, the principal dangers to be met with in diving, etc., have been dealt with in the preceding paragraphs. It is now appropriate to consider the practical application and uses of diving apparatus; the necessity for the various improvements mentioned; the special precautions to be observed in connection with diving operations; the manufacture, inspection, issue, care, preservation, and maintenance of diving apparatus, etc.

144. During the course of the deep-diving experiments over 300 tests were carried out. Of this number about one-half were in connection with diving experiments and the remainder were tests of diving apparatus. The following table will give an idea of the extent of the deep-diving tests:

Number of dives.	Pressure in pounds per square inch.	Equivalent depth in feet of sea water.	Number of dives.	Pressure in pounds per square inch.	Equivalent depth in feet of sea water.
5	0	0	13	55	122
8	2½	5½	3	60	132
1	5	11	4	65	144
1	10	22	38	75	168
6	15	34	4	80	179
1	20	46	4	85	190
7	25	57	9	90	201
1	27½	62	2	92½	207
5	30	67	3	100	224
10	35	79	2	105	235
6	45	99	9	110	246
6	50	112	1	115	258
3	52½	117			

Tests of apparatus.	Number.
Telephones, diving	76
Outlet valves, helmet	12
Control valves (new)	10
Diving air pumps	37
Diving gloves	6
Sling for divers (new)	5
Diving air hose	10
Morse diving apparatus	20
Schrader diving apparatus	20
Siebe-Gorman diving apparatus	10
Siebe-Gorman self-contained diving apparatus	12
Draeger self-contained diving apparatus	6
Diving tank	8
Dummy diver	3
Diving helmets	30
Draeger escape apparatus	5
Siebe-Gorman salvator apparatus	2
Ammonia helmet	1

In addition to and in conjunction with the foregoing many chemical, mechanical, physical, and electrical tests were accomplished.

145. *Record of experimental dives.*—The details of various experimental dives that are of interest are included in the records of experimental dives, inclosure (R).

146. *Deep diving.*—The tests have proved conclusively that diving to great depths is feasible and practicable providing certain changes are made in the diving apparatus and the rules and precautions applicable to diving operations are carefully observed. Any failure to follow these instructions are very liable to result in serious circumstances and probable disaster, hence the closest attention must be directed to all the details of methods and apparatus.

147. *Further information.*—While the deep-diving tests have accomplished the purpose required, i. e., the demonstration of improved methods of diving, the possibilities of deep diving, and the improvement of diving apparatus, they were, necessarily, limited to a short period of time, and additional and valuable information can certainly be acquired in practice. It is therefore necessary that the subject of diving shall be constantly studied with a view to further minimizing the dangers incident thereto and of further increasing the efficiency of diving operations. To this end records should be kept, classified, etc., as in connection with any other branch of military work, and from time to time printed instructions for the guidance of officers and men interested in diving should be published and issued as corrections or additions to Diving Manual.

148. *Improved methods of diving.*—It having been definitely proved that the present method (slow or uniform decompression) is inefficient, defective, antiquated, dangerous, and that the new method (rapid compression and decompression by stages) is incomparably

superior, it is apparent that a change in the method of diving as practiced in the Navy is necessary with the least delay. This change of the old for the new methods involves a considerable amount of detail and considerable preparation in order that the change can be accomplished without confusion, and within a reasonable length of time, however, it can be accomplished in this manner if the subject receives the necessary consideration and support. The military value of an efficient corps of divers to the Navy can hardly be overestimated' especially as the ships and vessels of the Navy become more and more self-sustaining and operate for longer periods away from a dockyard or repair station. Efficient divers, under favorable conditions, can perform the same quality of work under water as men of like skill can accomplish above water.

149. *Helmet diving.*—The natives of the Pacific Islands commonly dive to moderate depths by dispensing with the diving dress, shoes, and weights, and using only the helmet, air hose, and pump. The air supply to the helmet is supplied by the pump through a length of ordinary diving hose. The helmet is used as a diving bell and as a protection for the head only. The operation is usually conducted from a boat or platform as in the ordinary manner. The helmet as long as it remains right side up and is furnished with air at the pressure of the surrounding water will keep the water out. In practice the diving boat is rigged as in the ordinary manner and the helmet is weighted so that it will sink. When ready the helmet is lowered into the water, just below the surface and near the ladder, by means of the air hose and stopped to it so that it hangs in an upright position. The diver, dressed in woolen underwear and shoes (not weighted), descends into the water and ducks under and into the helmet, holding onto the edges of the breastplate. He is then lowered to the bottom by paying out on the air hose. As long as he keeps his head in an upright position and sufficient air is supplied to the helmet water will rise only to the level of the lowest opening; breathing is made easy; and in tropical waters diving in this manner becomes a comfortable operation. During the descent the diver must tread water and use some exertion to keep his feet down and his body in a vertical position. Proper balance in traveling up and down through the water is easily acquired with practice. When once down, due to a small negative buoyancy, the diver is able to retain his equilibrium without effort. Fortunately, in the past divers working in this manner, through fear of the water rising in the helmet, have, in most cases, invariably insisted on the pumps being run at a good speed to make sure of an adequate air supply, while unnecessary for the reasons generally supposed, i. e., that of keeping water out of the helmet is, however, essential to successful diving by any method due to the requirements of a proper air supply. It is apparent that with the

present form of regulating valve, which can not be entirely closed, a leak exists in the helmet at all times and at a high level. For this reason, if the pump is stopped or the air supply shut off in any manner, the air contained in the diver's helmet would leak out and the water would rise within it above his mouth and nose, thus making his position untenable. The leak from the regulating or exhaust valve is slight and easily overcome by the pump. However, it may happen, as when the pumpmen become tired and slow down the speed of the air pump, that just sufficient air would then be delivered to balance the leak from the escape valve and the pressure of water. In this case the diver would be on a short air supply and might be seriously affected by the products of his own respiration. The chances are, then, that he would not recognize his danger, and his mind being centered upon his work he would be liable to suffer loss of consciousness, consequently loss of stability, and be subjected to the additional danger of drowning. A recent fatal accident of this kind (see par. 140) may have been due to this particular cause. It is plain, therefore, that the precautions usually taken in regard to air supply while diving in this manner, even though inspired by fear and not by scientific reasoning, have, fortunately, been responsible for the success of the method known as helmet diving. When diving in this manner, and ready for the ascent to the surface, it is usual for the diver to throw off his helmet and to swim to the surface. For this reason the ascent must necessarily be rapid, and, if made from a considerable depth, the practice is dangerous owing to the liability of the development of symptoms of compressed-air illness incident to the rapid decompression. The use of the helmet only, therefore, for deep diving is impracticable on account of the difficulty of making a proper ascent to the surface. In attempting to imitate the native helmet divers in tropical water many Navy divers resort to the dangerous practice of securing the helmet to the shoulders by means of lashings with slip hitches, the use of life line, etc. Under no circumstances should any of the apparatus be secured to the diver in any manner. In case of accident to his air supply he will have no time to fumble with hitches, lines, apparatus, etc. His salvation will depend upon throwing the helmet off instantly and swimming to the surface. It is evident, then, that one of the principal qualifications of a helmet diver is that he shall be an expert swimmer. Also, that diving by this method should be limited as to depth of submergence and time of exposure to dangerous air pressures.

150. *Important helmet diving operation.*—It is interesting to consider the diving operations in connection with the raising of the dry dock *Dewey*, which sank in Subig Bay, P. I. All the diving was accomplished by naval divers under the immediate supervision of Gunner G. D. Samonski, United States Navy, and at the direction of

superintending naval constructor. The native Manila divers would not undertake the depth, which was in the neighborhood of 80 or 90 feet. The naval divers failed to accomplish anything by the use of the ordinary apparatus and attributed all their troubles to the temperature of the water and air supply which, being in the Tropics, was warm. There is no doubt whatever but that their failure was due to an ignorance of a diver's requirements as regards air supply and ventilation of the diving helmet. Gunner Samonski realized that if the dry dock was to be saved something must be done. So he tried the helmet method of diving and with success. The reason of his success is ascribed to the increased air supply. The temperature of water, etc., could not possibly have had anything to do with it. In this connection I may relate an experience of Gunner Samonski's as it was related to me. Mr. Samonski had made a descent to the bottom and had penetrated the interior of the dry dock by way of an open manhole. Suddenly his air supply failed; he threw off his helmet, swam back to manhole, passed through it, and ascended unaided to the surface, where he arrived in the nick of time and almost exhausted. Upon investigation he found that a sudden storm had caused the diving boat to be buffeted about so violently that the air pump had fallen overboard. His escape is regarded as very remarkable and one that emphasizes the importance of not fastening any useless lines or apparatus to the diver. For experiments in helmet method of diving see records of dives, inclosure (R).

151. *The method of diving with compressed air.*—The employment of compressed air in place of air furnished by hand pumps is a marked progress in the development of diving. Besides other advantages the possibility is offered to supply the diver at all depths with air in sufficient quantity. This does away with a fluctuating air supply, which can not be entirely avoided with manually-operated pumps. As compressed air is always ready in abundant quantity, the diver is enabled to keep the regulating escape valve on his helmet entirely open. Thus a lively exchange of air in the helmet is created excluding the possibility of any large accumulation of CO_2. The advantage of compressed air is especially noticeable in diving to great depths, as the diver supplied with air by hand pumps is compelled to throttle the escaping air in order to preserve the correct inflation of his dress. This causes faulty ventilation of the diving helmet and, in consequence thereof, a high percentage of CO_2. The following rules of conduct of the diver at great depths are based upon experience with compressed air only. They are therefore only valid for this kind of diving, and hold good for only the statements in the decompression tables governing the ascent to the surface. Other rules for divers not changed or eliminated by these instructions hold good for diving with compressed air.

152. The compressed air is taken from a low-pressure (100 pounds per square inch) air line. The air must be pure (free from oil fumes, etc.) as it is intended for breathing purposes. In pumping up the accumulators it must be strictly observed that the air does not come from the engine room, but is let in from the outside by means of an air duct or similar device. A minimum amount of oil should be used in the cylinders of compressors and the air should always be passed through a number of oil and water separators and, if practicable, through a series of strainers.

153. The diver controls his air supply by means of a special form of control valve (see inclosure (I)). The diving air hose when new is capable of sustaining an internal pressure of 500 pounds per square inch and the control valve will permit control of much higher pressures. For obvious reasons it would be unwise to operate at such pressures, and in as much as the low-pressure air lines furnish air at about 100 pounds pressure per square inch, only air at this pressure is considered. Should a higher pressure be necessary special arrangements would, necessarily, have to be made. It must be remembered that the pressure of the supply of air must always be at least 15 or 20 pounds above the pressure of the water in which the diver is submerged. Were the pressure equalized there would be no circulation or exchange of air within the helmet. The diver in regulating his air supply is guided by the inflation of his dress and the manner of his breathing. For instance, if his apparatus is pressing in upon his body too hard and breathing is quickened above the normal rate he knows that he requires more air and should open his control valve until the condition is relieved. On the other hand if, with his escape valve freely open, he becomes too buoyant he knows that the air supply should be throttled down. After the diver has regulated his air supply upon reaching the bottom no further changes of adjustment are necessary until he again changes the height of his position in the water. Three special dangers are to be carefully guarded against, "falling," "blowing up," and "bursting of the air hose." The former two have been previously dealt with. The latter is liable to occur only at or near the surface. This danger is not an imminent one if the air hose is in good condition. As a precaution the air hose should always be tested to a higher pressure than that at which the diver is going to work.

154. The attendant should be a skilled diver. He must strive to constantly "feel" the diver on his lines and at the same time not interfere with his (the diver's) work. In many cases this can not be done, however, for instance, with work in a stream, or with work on a high object, such as a submarine, where he could easily be brought to fall by a side pull. The lines must be gripped firmly in order to be able to hold on tightly if the diver should fall If the diver is "blown up"

through some accident, follow the directions contained in paragraph 134.

155. In compressed-air diving to great depths, owing to the increased amount of noise in the helmet in consequence of the increased air supply, telephonic communication becomes more difficult; however, by throttling the air supply and air exhaust for a few minutes at a time it is made possible. The diver can usually be clearly understood, unless his voice is affected by great pressures, and a comprehensive code of signals should be arranged that will cope with any probable situation. Air-control signals are unnecessary as the attendant has no means of control. Incidentally the pressure gauges on the diver's supply line give no indication of the depth of the diver from the surface and during decompression are of no value as a check upon this location unless the supply be temporarily cut off. This procedure if attempted must be very carefully done in order to prevent a "squeeze." The method recommended for indicating to the diver when to stop at different depths is by using a Jacob's ladder with the rungs spaced according to the proper stages. If it is weighted on the lower end so that it hangs up and down in the water the diver has simply to ascend until he comes to the first rung, which will be the first stage or stop of decompression. The whole ascent must be carefully timed and the diver informed by signal when to proceed from stage to stage. In coming up the diver so regulates his buoyancy that with slight effort he can climb hand over hand to the various stages. He always keeps the descending line well in hand so that he may judge his speed through the water. If he finds himself floating upward too rapidly, he must exhaust some of the air in his dress quickly to prevent losing control of himself and his apparatus. This can be accomplished by elevating an arm and allowing the superfluous air to escape by the elastic cuff at the end of the sleeve of the dress or he can open the "spit cock" (supplementary relief valve) and close the control valve, at the same time checking the ascent by gripping the descending line tightly with his legs and hands. As soon as the positive buoyancy is lessened he must again readjust his valves or else he will become so heavy that he will not be able to hold on to the descending line and will commence to slip down toward the bottom, thus courting the danger of a "squeeze." The control of valves under ordinary situation is quite simple and the divers learn the method of compressed-air diving very quickly. In fact it is all so simple and easy that there is a tendency toward recklessness upon the part of most men and this should be carefully guarded against as a great danger. Extreme caution under water is the fundamental qualification of a deep-sea diver.

156. *Advantages of diving with compressed air.*—In addition to the advantages mentioned in paragraph 151 the method of compressed-

air diving requires fewer men as attendants. The ordinary pumping crews are entirely dispensed with. The method is particularly well adopted to small vessels on which there is no room to stow diving pumps and bulky apparatus; it is also of advantage when deep diving is necessary and only small boats are available to work from. In this case a supply of highly compressed air in tanks or torpedo air flasks can be carried in a sailing launch or cutter rigged for diving. Connections to the diving manifolds are made by means of the flexible copper charging pipe and suitable reducing valves. A gauge is fitted in the air lines so that a check can be kept on the air pressure on either side of the reducing valve. Under ordinary conditions a torpedo air flask will contain sufficient air, if fully charged, to last the diver a considerable length of time, and is a most convenient arrangement. Air received by the diver in this manner is always cool, due to expansion. In warm water this is an advantage and in cold water a disadvantage; however, experience indicates that special provisions for regulating the temperature of the air supply are unnecessary except in extreme cases.

157. *Possibilities of deep diving.*—To date no difficulty has been experienced in diving to a little over 40 fathoms. It may be useful, however, to consider the possibilities of practically useful work at greater depths, and of extending the time on the bottom at depths exceeding 20 fathoms. One difficulty not hitherto referred to arises from the fact that at depths exceeding about 25 fathoms the pressure of oxygen in the air breathed by the diver begins to be capable of producing serious effects. It has been found by experiments carried out in European countries that oxygen at high pressure acts as a poison. At an absolute pressure exceeding about three atmospheres of oxygen (corresponding to about 15 atmospheres of air pressure, since air contains about a fifth of its volume of oxygen) animals go into convulsions and soon die, even a short exposure being often fatal. With an exposure of several hours, a pressure of even two atmospheres of oxygen, or 10 atmospheres of air, was found to be dangerous. To judge from the experiments along these lines it seems probable that in all possibility a man supplied with air in the usual way might dive to about 400 feet for a short time without much risk of ill effects from oxygen pressure, and that an exposure of two or three hours at 300 feet would not be dangerous. To breathe pure oxygen for long at pressures much exceeding two atmospheres absolute is evidently risky, and at a pressure of three atmospheres is dangerous. In order to avoid the risks arising on decompression from bubbles of nitrogen it has been proposed to supply divers with pure oxygen. Pure oxygen, however, can not be safely supplied for any considerable time at depths exceeding about 6 or 7 fathoms.

158. As already pointed out, the troubles arising from pressure of CO_2 in the helmet air can be overcome by increasing the air supply, pumps driven by power being substituted if necessary for hand pumps. There are, however, methods by which the amount of air required can be diminished.

159. The most serious difficulty in connection with deep diving is undoubtedly that due to the dangers of decompression. The means available for obviating these dangers under ordinary conditions of diving work have been dealt with. Various further measures might, however, be adopted for special cases. In this connection submarines fitted with diving compartments provide an ideal means for conducting prolonged deep-diving operations. The boat can be moored with positive buoyancy at a safe distance below the surface of the water and the diver can pass in or out without any of the vexatious delays due to adverse weather conditions. The length of his lines are shortened, and thus the effects of the tide upon them are lessened. The diver would get to his work in less time, and when ready could return rapidly to the diving compartment, and would thus be spared the long and tedious ascent through the water that would be necessary were the operation conducted from the surface. After returning to the diving compartment, he could be decompressed at leisure after a wait sufficiently long to make the process safe. If he were required to ascend all the way to the surface, he would be exposed to the risk of his hands becoming numbed from cold, so that he could not hold onto the descending line. If, as is often the case, the tide is formidable, the risk of being carried away from the descending line is considerable, and a diver thus carried away will probably come to the surface at once and so be in danger of the consequences of sudden decompression. Another advantage of this arrangement would be that in the event of any symptoms occurring the diver could be recompressed at once.

160. A submerged decompression chamber or a combination diving bell and recompression chamber would, under favorable weather and surface conditions, answer the purpose as well as the submarine. However, it would be unwieldy, cumbersome, and difficult to handle. In a seaway it would be especially hard to manage. With the diving bell the diver could be brought rapidly to the surface, the pressure inside being lowered at a safe rate. The bell would be landed on deck of the working vessel, and, if fitted with observation windows and an air lock, the diver could be kept under medical observation, etc. By means of the air lock food and dry clothing could be passed into him. Another advantage would be that in the case of threatened danger, such as an approaching storm, the diving work could be abruptly terminated without danger to the diver.

161. *Diving apparatus on destroyers and submarines.*—By the adoption of the compressed-air method of diving the problem of providing a suitable diving apparatus for small vessels in the Navy is adequately disposed of. All the necessary apparatus for one diver can be contained in a single sea chest, and the total weight is much less than that of the ordinary outfit. I am informed indirectly that diving apparatus now furnished for these vessels and carried on board the parent vessels is in an unsatisfactory condition. This is probably due to improper stowage and an indefinite personal responsibility.

162. *Inspection of diving apparatus.*—The methods of inspection for diving apparatus are at present very lax and are, in a general way, responsible for many of the unsatisfactory conditions in connection with this material. When new apparatus is received from the manufacturers, the inspection of the material is generally intrusted to an inexpert civilian subinspector. His only guide for making the inspection is, at present, the specifications for the manufacture of diving apparatus. These specifications are incomplete, hence a greater portion of the material is given a surface inspection only, and the inspector's principal concern is to see that the quantities are correct. With the exception of the diving air hose, no physical, mechanical, or chemical tests are made. To the credit of the various manufacturers of diving apparatus, it may be noted that very little trouble has so far been experienced with shoddy material or workmanship. However, as greater demands upon the efficiency of diving apparatus will be made in the future, more definite and detailed inspections of diving apparatus should be insisted upon. When issued to ships, the diving apparatus, if new, is accepted without question. After issue, in no case does the diving apparatus receive the proper care and attention. In this regard there are no official or detailed instructions for its use, care, preservation, etc.

163. *Specifications for the manufacture of diving apparatus.*—The present specifications for the manufacture of diving apparatus are incomplete, and therefore do not insure the proper material being furnished. The specifications for diving apparatus, 12–D–1, dated December 5, 1912, merely state what articles should compose an outfit of diving apparatus, together with indefinite general specifications for a few of these articles. The nearest approach to a correct specification for any one article is in the case of the diving air hose. In this it is stated that the inside diameter of the hose is to be one-half inch, no mention being made as to what the dimensions of the outside diameter or the size of the couplings should be. In the service we have an assortment of sizes. The specifications for diving air hose is merely an instance, all other specifications for diving apparatus being less complete. In accordance with the bureau's instructions the

specifications for diving apparatus are being revised and will be forwarded for approval at an early date.

164. *Tests of diving apparatus to be made during inspection.*—At present the only tests of diving apparatus required by the specifications are physical and chemical tests of the air hose. In this respect the instructions are as follows:

(*a*) The tube and cover to be made of a properly vulcanized rubber compound, which shall show on analysis not less than 25 per cent of fine Para rubber and not more than 2½ per cent of sulphur, the remainder to consist of dry inorganic mineral matter only. The mineral matter may contain barytes, but must be practically free from sulphur in any other form. The fabric to consist of five plies of 12-ounce cotton duck. The rubber used in friction to be pure Para of good quality.

(*b*) The hose to be so constructed as to be capable of withstanding 500 pounds per square inch hydrostatic pressure for 10 minutes. However, only 1 length out of every 10 lengths to be subjected to the above pressure test, the remaining lengths to be subjected to only 200 pounds for 2 minutes.

NOTE.—Additional tests for proving the efficiency of other parts of the diving apparatus are necessary. The diving pumps should be tested for leakage; screw threads should be tried by standard gauges; the insulation resistance, conductivity, and continuity of circuit of telephone cables should be tested; the quality of rubber and woolen goods should be proved, etc.

165. *Care and preservation of diving apparatus.*—The diving apparatus should always be ready for instant use. Unless properly stowed and cared for certain parts of the apparatus will deteriorate and get out of order. Speaking generally, the diving gear should be cleaned up every week, the pump hove round several turns, helmets and valves in them wiped over, all lanyards attended to, telephone batteries tested, telephones tried, dirty woolens washed and aired, and the dresses examined to see if they are damp. If the lengths of air hose have been connected up for long they should be parted, the threads lightly oiled, and new washers inserted. Heavy oiling in any case is a mistake, as oil rots and spoils any rubber gear that comes in contact with it. Very little oil should ever be allowed inside the pump cylinders. Pumping parties confronted with a stiff pump have often been known to empty an oil can in through the oil cups, thus clogging the outlet valves and allowing the lubricant to flow into the air hose. During the tests an air hose burst at 100 pounds pressure from this cause. The proper method of lubricating the piston in a diving pump is as follows: The piston is brought to the top of the cylinder, the cup filled with oil, and cup is then opened. The piston is drawn to the bottom of the cylinder, sucking in the oil

as it descends. The oil cock must then be closed; if the cock were left open the cylinder would deliver no air on the upstroke. During steady diving work one such oiling a day is sufficient. When laid up the pump should not need oiling more than once in a quarter.

166. *Care of diving pumps.*—Before stowing the pump away the water should be drained out of the reservoir and any condensed moisture should be wiped off. The lid should be left open a couple of hours for it to cool off, when the working parts should be lightly oiled over. The pump should be stowed under cover and away from excessive temperatures. The pump should be hove round a few turns every week. It is a great mistake to strip the pump down unless absolutely necessary. The only internal parts likely to require attention are the valves, and instead of stripping down the whole pump they may be removed every few months and dirt or verdigris removed from the disks and seatings, the springs being removed if necessary. The springs of the bottom inlet valves are specially liable to break and should be carefully watched. If the pump has to be stripped, a clean tarpaulin should be spread and every care taken to prevent grit getting on the leathers or into the cylinders. The diving pump is really an engine or a machine, and its overhauling, etc., should be accomplished in the manner in which an engineer would do it. Parts should be removed in order and assembled as carefully. The adjustment of bearings, setting up on stuffing boxes, etc., should be carefully done. A diving pump should never run easily, but setting up the bearings and stuffing box gland nuts too tightly will cause an unnecessary amount of friction and add to the labor of pumping. The caps of bearings should be the same distance apart at their ends, with the securing bolts moderately tight. The caps for protecting the ends of the crank shaft should be habitually kept shipped in place and these projections should never be used in moving or lifting the pumps about. In slinging the pump, preparatory to hoisting, the strap or sling should be passed through the securing bolts, which are made specially strong for this purpose. The practice of painting the pump and other diving apparatus chests different colors should be discontinued. The chests are of hardwood, finished, and varnished, and care should be exercised to keep them bright and clean. If the apparatus is kept in a slovenly manner deterioration soon results. Its handsome appearance instills a pride and carefulness that insures efficiency and economy.

167. *To replace worn cup leathers on piston.*—Remove the piston, file off the burr at the end of the rod, unscrew the nut securing the pistons and remove the old leathers, open two of the tins supplied, each containing a cup leather with spring in oil, wipe off superfluous oil, fit them in position and secure the nut as before, being

careful to burr over the piston rod sufficiently to make it impossible for the nut to slack back. If the nut did slack back it would, of course, happen while the pump was working, with probably a diver below; as the clearance at the bottom of the cylinder is very small, the pump would quickly be brought up and the consequence might be serious.

168. *Piston-rod glands.*—These frequently are a source of leakage. If the pump is working at high pressure, open the lid occasionally and listen for the blowing noise caused by air escaping at this joint; if in doubt sprinkle a little water at the point where the rod emerges from the gland and it will show by sputtering if a leak exists. The pump must be actually working; it is useless to look for a leak with the pump stopped, whatever pressure there may be on the gauge. If leakages occur, the glands can be tightened or repacked.

169. *Care of helmet.*—The helmet should be kept screwed onto the breastplate, the brasses shipped, and the wing nuts screwed onto the studs; this is to prevent damage to the threads. The helmet should be wiped out inside with a dry cloth so as to prevent the accumulation of moisture rusting the diaphragm of the transmitter. If, as the result of wear, the helmet, when screwed hard onto the breastplate, will go so far around to the right that the catch at the back of the helmet is past its recess and the front glass is not directly in front of the diver's face, one or more paper washers should be cut and inserted under the large leather washer at the neck of the breastplate, or a spare washer fitted. Helmet valves should be kept clean and lightly coated with a mixture of neat's-foot and olive oil in equal parts.

170. *Breastplate and brasses.*—Once the brasses have got out of shape it is extremely difficult to make good joints. The causes of the brasses getting out of shape is the pernicious practice of screwing the wing nuts down too tightly. The attendant who uses all his force in screwing up these small nuts with the wrench provided imagines that he is making a thoroughly water-tight joint whereas, in reality, he is only bending the brasses and making the suit leaky for the rest of its service. To make a good joint the wing nuts need be set up only moderately tight. The wings of the nuts should be left fore and aft so as to clear the helmet when it is screwed in place.

171. *Care of air hose.*—If a long length of air hose has been in use condensed moisture is sure to have accumulated in it, and the hose should be triced up to drain before being coiled away in its chest. The hose and all other rubber goods should be stowed in a cool place, for the rubber blisters and deteriorates from the effect of heat. Every precaution must be taken to protect rubber goods from coming in contact with oil or grease.

172. *Care of diving dresses.*—The diving dress should be cleared of mud, etc., and if wet inside turned inside out and hung in the shade

to dry; the dresses if used in salt water should be washed in fresh water at least once a week. On no account must they ever be packed away in a damp state; they must be thoroughly dried both inside and out, otherwise they will mildew and become so rotten as to be a source of danger. The following is an easy and efficient mode of drying the diving dress: Take two pieces of wood about 8 feet long, nail or screw them together in the form of St. Andrew's cross, place them inside the dress, and pass another piece through the arms to keep them distended. The dress can then be leaned at a slight angle until it is dry. In case the diver urinates in the dress it should be turned inside out and washed with clean water, and then allowed to dry. Diving dresses should, if possible, be hung up in special locker or room and not be kept folded up in a chest.

173. *Repairing diving dresses.*—Prepared twill and india-rubber solution are provided for repairing leaky dresses. If the leak is due to a tear, first wash the place in fresh water and thoroughly dry it. Cut two patches of twill of the size and shape required—one for the outside and another for the inside of the dress. Three coats of solution are applied round the tear, each being allowed to dry a couple of hours before the next is put on. Applying on coat of solution to the india-rubber side of the prepared patch, put the latter in place. The patch may be smoothed down with a warm flatiron. A flat weight should be placed on the patch to keep it down while drying. As soon as one side is dry the other can be repaired in exactly the same way. If the leak is due to an imperfect seam in the dress, a quick repair can often be effected by rubbing solution into the channel of the seam. If this does not answer, a long strip of twill must be applied in the form of a patch to the outside of the seam. Carelessness in handling is the principal cause of injury to diving dresses. The rubber cuffs and collars are frequently torn from this cause and for which there is no excuse. New rubber cuffs are attached in the same manner in which a patch is put on. The rubber collars are sewed and cemented to the dress and the operation requires considerable skill to make the repair a neat one and the joint strong and waterproof.

174. *Care of diving telephone.*—If handled with care and intelligence telephone gear will last a whole commission and be of the greatest use to divers. Unfortunately very little trouble has generally been taken about it on board ship, and the gear does not work at all. The first thing is to prevent the diaphragms from rusting. The helmet, like everything else, ought to be thoroughly dry before it is put away. Always keep the box shut if it is raining, and if a helmet is in the boat, but not in use, do not let rain or spray get inside it, but ship the face plate and stand it right way up. Continuity often fails through the wires breaking a few inches from

either end of the breast rope. Care must be taken to prevent the rope getting a sharp bend or nip at these points, which is the cause of the trouble. Insulation often breaks down through trying to force the spills through wrong holes when connecting breast rope to helmet or through violently shaking at the breast rope when disconnecting it and withdrawing the spills. Good contact must be got by keeping the spills and connections bright and clean, not oiled. It is of no avail to use two hands on the telephone spanner and try to make contact by brute force. After a day's diving, if the telephone has got out of order it should be sent to the ship's electrician for repairs at once and never stowed away unless it is in thorough working order. It should be tested weekly when the diving gear is cleaned and will be found ready when wanted.

175. *Care of diver's knife.*—After use it is to be dried, cleaned, sharpened if necessary, and not put back into the sheath until the latter is perfectly dry.

176. *Proposed changes in Navy diving outfit.*—The following tables show the composition of the present Navy diving outfit and the changes that are recommended:

Article.	Present.	Proposed.
1. Diving air pump	1	1
2. Flywheel	2	2
3. Joint, union, double male	1	1
4. Joint, union, double female	1	1
5. Can, oil, feeding	1	1
6. Nut, for securing pump handles	3	3
7. Screwdrivers	2	2
8. Spanners, double ended	3	2
9. Washers, leather, for joints of air hose (spare)	12	24
10. Leathers, cup, piston, spare, with springs, packed in oil, in tin boxes	0	4
11. Valve, pump, complete, with spring, leathers, and cotter pin	4	4
12. Studbolts, for breast plate of helmet, spare	6	6
13. Nuts, for breast plate, spare:		
Small	8	8
Large	4	4
14. Springs, inlet, for helmet, spare	1	1
15. Springs, outlet, for helmet, spare	3	3
16. Helmet, with safety and regulating valves	2	2
17. Chests, helmet, with lock and key	1	1
18. Chests, outfit, with lock and key	2	3
19. Dresses, rubber, diving	2	2
20. Rings, wrist, rubber	12	36
22. Wristlets, woolen, pairs	6	0
23. Shirts, woolen, medium	6	4
24. Shirts, woolen, heavy	0	4
25. Drawers, woolen, medium	6	4
26. Drawers, woolen, heavy	0	4
27. Expanders, cuff, sleeve	2	2
28. Stockings, woolen, pairs	6	8
29. Overalls, canvas, with adjustable straps	2	2
30. Caps, woolen	2	0
31. Dress, canvas, overall	1	0
32. Neckerchief, cotton	2	0
33. Signal lines, 120 feet	2	0
34. Shoes, with lead soles, pairs	2	2
35. Diving weights, belt pattern	2	2
36. Diving weights, horseshoe pattern	0	2
37. Snap tubing, feet	3	6
38. Knives, diving, in cases	2	2
39. Rubber cement, 2-pound can	1	1
40. Rubber repair cloth, yard	1	2
41. Frames, screw, for helmet	2	0
42. Glasses, helmet, spare, set	2	1

Article.	Present.	Proposed.
43. Rubber diving mittens, with rings and clamps, pairs	2	0
44. Urinals, improved	2	2
45. Woolen mittens, pairs	2	0
46. Shackles, or crinoline	1	0
47. Helmet cushions	2	2
48. Spanner, helmet nut	1	0
49. Wrench, socket, "T"	1	2
50. Wrench, monkey, 6-inch	1	1
51. Wrench, monkey, 10-inch	1	1
52. Cutting punch	1	1
53. Hose, air, 50-foot lengths	6	8
54. Belts, leather, for knife	2	2
55. Telephone outfit, complete	2	2
56. Test tank, 1 cubic foot capacity	0	1
57. Under jacket, with diving gloves attached	0	2
58. Woolen gloves	0	2
59. Diving ladder, folding	0	2
60. Air-control valve	0	2
61. Short lengths diving hose (3-foot)	0	4
62. Reducing valves	0	2
63. Manifold	0	1
64. Test gauge	0	1
65. Cyclometer, with fittings	0	1
66. Descending line, 3-inch, tanned rope, cable laid, 150-foot, lengths	0	2
67. Distance line, tanned rope, cable laid, 15-thread, 50-foot lengths	0	2
68. Mushroom anchor, 50 pounds	0	4
69. Mushroom anchor, 100 pounds	0	1
70. Cork buoys, 12-inch	0	4
71. Tool for assembling pistons in cylinders of pump	0	1
73. Adapter for connecting charging pipe of torpedo air flask to manifold	0	2
74. Diving lanterns, electric	2	2
75. Turn buckles, for securing diving pumps	0	4
76. Jacob's ladder, 90 feet	0	2

177. In the table showing proposed changes it will be noted that such articles of diving equipment that have been found to be obsolete or unnecessary are omitted and certain new and additional articles that are essential have been added.

178. *Reasons for adding additional articles to the Navy diving outfit.*—Referring to the list, in preceding paragraph, in numerical order—

Article 9: The number of washers for air hose is doubled. This is necessary and adds practically nothing to the cost of diving apparatus.

Article 10: A diving pump is liable to develop abnormal leakage of air past the pistons and which destroys its efficiency. The only remedy is to replace the piston leathers. The spare leathers should be packed in neat's-foot oil in sealed tins. A spare set should always be on hand.

Article 18: At the present time the number of outfit chests will barely contain the articles of diving equipment, and as additional apparatus is recommended an additional chest is a necessity.

Articles 20 and 37: The number of rubber wrist rings is tripled. These are necessary and inexpensive.

Articles 24 to 28, inclusive: At present only one grade of underwear is furnished. Experience has proven that for work in cold climates an additional heavier grade is a necessity.

Articles 22, 30, 31, 32, 33, 41, 43, 44, 45, 46, and 48: These articles are either obsolete or unnecessary and should be abolished for the reasons stated in preceding paragraphs.

Article 40: Diving dresses are often condemned as useless on account of slight defects that could be easily repaired by following the instructions contained in paragraph 173. Instead of permitting a hole to wear through a dress, a patch should be cemented over the part showing wear. Renewal of patches occasionally would keep the dresses in good condition. Surveying officers, when passing upon damaged diving apparatus, usually follow the reasoning that as a man's life depends upon the integrity of the apparatus he should condemn the article in question. If the divers were required to make their own repairs and new apparatus was denied them until it was clearly proven that the article in question was beyond repair, the resulting economy would be considerable. Barring unavoidable accidents, an outfit of diving apparatus should easily last several years; at least a full commission.

Article 53: As the divers learn to dive to greater depths and at all depths more efficiently, the amount of diving hose furnished becomes inadequate.

Article 56: A small test tank of 1 cubic foot capacity, with suitable connections and fittings, is necessary for use in proving the efficiency of diving air pumps. It can also be advantageously employed in many other ways in connection with diving operations, etc. A tank such as shown in the sketch, inclosure (S), will answer the purpose and will occupy but little room on board ship.

Article 57: As a protection to a diver from cold and in lieu of the present form of rubber diving mittens, it is recommended that underjackets, with diving gloves attached, as shown in sketch, inclosure (N), be furnished.

Article 59: A suitable diving ladder is an absolute necessity and is an article not now supplied. It is recommended that a standard article such as shown in the sketch, inclosure (T), be furnished.

Article 60: Air-control valves are an important improvement to diving apparatus and in all cases should be supplied as a part of the regular equipment. For sketch and description, see inclosure (I).

Article 61: Required for use in connection with article 60.

Article 62: In case it becomes necessary to dive with compressed air and high-pressure air only is available, as when using air from torpedo air flasks, suitable reducing valves are necessary. The proposed arrangement of valves and piping are shown in sketch inclosure (U).

Article 63: Is required for use in connecting two or more diving pumps to a diver's air-supply hose or for connecting two or more diver's supply hose to a single source of air supply.

Article 64: It is desirable that a suitable test pressure gauge be furnished with each diving outfit; is especially useful in connection with the compressed-air method of diving.

Article 65: Required for use in connection with testing and proving efficiency of air pumps, and to avoid errors in counting the revolutions of diving pumps under test.

Article 66: Tanned rope does not become slippery under water, and as in deep diving a diver spends much of his time holding onto the descending line during the ascent, rope of this kind adds much to his safety and efficiency.

Article 67: By the use of a distance line a diver is able to find his way over the bottom with greater facility in dark waters than by blindly groping around without it.

Article 68: A 50-pound lead weight should always be fastened to the end of the descending line to keep it on the bottom and also as an anchor for one end of the distance or circulating line. It is useful also for anchoring marker buoys and in sending lines down to the diver.

Article 69: For use in a stream or tideway where the 50-pound weight is not sufficient. In case this is not heavy enough it can be used in combination with a 50-pound weight. The mushroom type is recommended because, being smooth, it is not apt to foul other lines when being either raised or lowered.

Article 70: Cork buoys are intended for use in defining areas of diving operations, marking special locations, etc.

Article 71: Pistons for diving pumps fitted with spring rings can not be assembled without injuring the leathers except by the aid of a special tool. See sketch, inclosure (V).

Article 72: Required for use when it is necessary to couple two telephone cables together.

Article 73: Self-explanatory.

Article 74: The present number (2) of diving lanterns supplied to a vessel is inadequate. One light should be carried for each diving helmet.

Article 75: When deep diving is undertaken it is practically impossible to lash diving pumps so they will not wobble around. The least slip greatly increases the labor of pumping and causes an irregular speed of the pumps that is objectionable. Diving pumps can be neatly and rigidly secured by the use of turnbuckles.

179. *Number of diving outfits to be carried by various vessels.*—It is recommended that all large vessels carry two complete diving outfits, as is the case at present. If they are kept in efficient condition, the facilities for diving will be sufficient to enable four divers to work at the same time in shallow water (30 feet or less) with a small reserve air supply; two divers in moderately deep water (60 feet or less); and

one diver in deep water (120 feet or less). Except in cases of emergency the limits of diving depths, as given above, should not be exceeded, as it is more or less dangerous to dive under water without a reasonable reserve air supply to draw upon in case of accident. In cases of diving work where a diver may be in danger of getting foul a second diver should always be ready to go to his assistance. If the diving is being undertaken in depths over 60 feet and where it is necessary to couple two pumps together, this would not be possible with the apparatus furnished a single vessel. Hence the precaution must be taken to borrow additional apparatus (pumps) from another vessel, or, if acting singly, preparations should be made to dive by the use of compressed air, when as many divers as necessary may be sent down without difficulty. A single diving outfit is sufficient for small vessels, such as gunboats, light cruisers, and auxiliary vessels. Such vessels do not, as a rule, carry torpedoes and would seldom require any deep diving to be done. In special cases special apparatus could be provided. Referring to the second table in paragraph 166, the following articles would constitute an outfit of diving apparatus for destroyers:

Article.	Amount.	Article.	Amount.
1. Joint, union, double male	1	28. Glasses, helmet, spare, set	1
2. Joint, union, double female	1	29. Helmet cushions	2
3. Screw drivers	2	30. Wrench, socket, "T"	2
4. Washers, leather, for joints of air hose	24	31. Wrench, monkey, 6-inch	1
5. Stud bolts for breastplate of helmet	6	32. Wrench, monkey, 10-inch	1
6. Nuts for breastplate:		33. Cutting punch	1
Small	8	34. Hose, air, 150 feet lengths	6
Large	4	35. Belts, leather, for knife	2
7. Springs, inlet, for helmet	1	36. Telephone, complete outfit	1
8. Springs, outlet, for helmet	3	37. Underjacket, with diving gloves attached	2
9. Helmet, with safety and regulating valves	2	38. Woolen gloves, pairs	2
10. Chest, helmet, with lock and key	1	39. Diving ladder, folding, special	1
11. Chest, outfit, with lock and key	2	40. Air control valve	2
12. Dresses, rubber, diving	2	41. Short lengths diving hose (3 feet)	4
13. Rings, wrist, rubber	36	42. Reducing valves	1
14. Expanders, cuff, sleeve	2	43. Manifold	1
15. Shirts, woolen, medium	4	44. Test gauges	1
16. Shirts, woolen, heavy	4	45. Descending line, tanned rope, cable laid, 3-inch, 150 feet	1
17. Drawers, woolen, medium	4		
18. Drawers, woolen, heavy	4	46. Distance line, tanned rope, cable laid, 15-thread, 50-foot lengths	1
19. Stockings, woolen, pairs	8		
20. Overalls, canvass, with adjustable straps	2	47. Mushroom anchor, 50 pounds	2
		48. Mushroom anchor, 100 pounds	1
21. Shoes, with lead soles, pairs	2	49. Cork buoys, 12-inch	4
22. Diving weights, belt pattern	2	50. Coupling for telephone cable	1
23. Diving weights, horseshoe pattern	2	51. Adapter for connecting charging pipe of torpedo air flask to manifold	2
24. Snap tubing, feet	6		
25. Knives, diving, in cases	2	52. Diving lanterns, electric	2
26. Rubber cement, 2-pound can	1	53. Jacob's ladder, 90 feet	1
27. Rubber repair cloth, yard	2		

NOTE.—It will be noted that the diving pump and its accessories have been eliminated and the number of chests reduced to three. Diving with this apparatus will, of necessity, be accomplished by the compressed-air method only, direct from the side of the vessel. In case of a distant operation, as from a sailing launch, the boat would have to be borrowed from a larger vessel and torpedo-air flasks used to contain the diver's air supply.

180. *Apparatus for submarines and small torpedo boats.*—The composition of the diving outfit recommended for use on submarines and small torpedo boats is as follows:

Article.	Amount.
1. Joint, union, double male	1
2. Joint, union, double female	1
3. Screw driver	1
4. Washers, leather, for air hose	12
5. Chest, outfit, special	1
6. Dresses, diving	1
7. Rings, wrist, rubber	12
8. Expanders, cuff	2
9. Shirts, woolen, medium	2
10. Drawers, woolen, medium	2
11. Stockings, woolen, pairs	2
12. Shoes, diving, pair	1
13. Diving weight, belt pattern	1
14. Knife, diving, with belt	1
15. Rubber cement, can, 1-pound	1
16. Rubber repair cloth, yard	1
17. Helmet cushion	1
18. Wrench, socket, "T"	1
19. Hose, air, 50-foot lengths	4
20. Telephone outfit, special	1
21. Underjacket, with gloves attached	1
22. Woolen gloves, pair	1
23. Air-control valve	1
24. Helmet, with safety and regulating valve	1
25. Short lengths diving hose (3 feet)	2
26. Adapter for connecting air hose to low-pressure air line	1
27. Descending line, tanned rope, 3-inch, 150 feet	1
28. Distance line, tanned rope, cable laid, 15-thread, 50 feet	1
29. Mushroom anchor, 50 pounds	1
30. Diving lantern	1

NOTE.—In this case apparatus is listed for one diver only, compressed-air method, and is to be contained in a single chest. In case of complicated or dangerous work (where there is a risk of the diver getting fouled) the diver from another boat should stand by. Spare apparatus could be carried on board the submarine tender.

181. *Preparations for diving work.*—In cases where deep diving is to be undertaken it should, if practicable, be accomplished by the compressed-air method and every precaution taken to guard against accident. Skilled attendants and special facilities arranged. Nothing should be left to chance. Definite plans of procedure should be mapped out ahead of time and all possible emergencies provided for. It is apparent that in deep diving an exact knowledge of the art of diving is essential and that local conditions at the surface and on the bottom must be considered. Periodical drills at practical work will do more than anything else to indicate what special preparations will be necessary and to maintain the efficiency of the diving party at a high standard of excellence. Ordinarily diving operations at sea are conducted from small boats at a distance from the vessel to which they belong. Sailing launches are the most suitable for this purpose and, when possible, should be used in preference to others. Provisions should be made in this type of boat for securing the diving pumps. This can best be accomplished by fitting screw sockets in which may be screwed four eyebolts. By means of suitable turnbuckles the diving pump can be rigidly and neatly secured. When not required for the purpose mentioned the eyebolts can be removed, flat-headed bolts screwed into the sockets to keep them from filling with sand or dirt and to protect the threads and the eyebolts and turnbuckles stowed in the diving chest. The diving pump should be arranged in the boat out of the way of the diver and attendants and so that a clear view of the gauges will be

afforded the latter. Diving pumps should always be worked in their cases and the cranks revolved in the direction of the gauges or toward the front of the pump, starting from the top of the stroke. In this direction the nuts keeping the crank handles in place will tend to tighten and prevent the possibility of the handles working off, as sometimes happens when the pumps are operated in the reverse direction. When operating at a distance from a vessel the diving boat should always be attended by another boat (pulling boat or launch) fully manned. The tender may be required for many purposes, such as assisting the diving boat to change its position, carry out lines, pick up or shift marker buoys, run errands, etc. It is not safe to permit a diver to descend or to remain under water during a heavy fog, and, in all cases, care must be taken to prevent the diving boat from being run down by another vessel. A red flag should be hoisted in the diving boat by day and at night it should be illuminated by the ship's searchlight.

182. *Tests to be made before sending diver under water.*—The safety and efficiency of the diver depends upon the proper functioning of his apparatus, and it should be carefully tested at the commencement of each day's diving work.

183. *Testing diving pumps.*—The method of ascertaining the leakage of the diving pump is stated in paragraphs 29 to 35, inclusive, and if the pumps are tested and cared for as per the instructions contained in paragraphs 165 to 169, inclusive, further tests are unnecessary. If, however, for some adequate reason the periodical tests have been neglected, each cylinder and all the piping and connections must be carefully tested and inspected, following the instructions quoted above.

184. *Testing gauges.*—For bringing up a diver safely from deep water and for testing the pumps it is very important that the error of the gauges should be accurately known. A length of air hose is to be joined up to the pump and carefully measured off and marked at every 10 feet from the free end of the hose. A sinker is then secured to the end of the hose and the hose lowered overboard at slack water while heaving round on the pump till the 10-foot mark is awash. The pump is then stopped while the gauge is lightly tapped and its reading taken and recorded. The pump is then hove round while the hose is lowered another 10 feet, when the process is repeated, and so on. The hose must of course hang up and down in the water, so the test should be done at slack water, or if a boat be used it may be allowed to drift with the tide. The results are to be tabulated as in the following example and pasted in the lid of the pump, where they can readily be referred to and the necessary correction applied when bringing up a diver:

Result of test of left gauge, carried out Sept. 25, 1914.

True depth.	Gauge shows.
Feet.	*Feet.*
10	5
20	17
30	28
40	38
50	49
60	60
Etc.	Etc.

NOTE.—The test should be repeated every quarter or oftener if error is suspected. The gauges can be changed over so as to bring the more accurate one to the left side, as it is the left gauge that is used in bringing up a diver.

185. *Testing nonreturn valves on helmet.*—Remove valve from gooseneck on helmet and screw it on end of hose in reverse manner. Pump air up to 15 or 20 pounds pressure and immerse valve in water. If the valve leaks, bubbles will be seen escaping from it into the water. Before screwing the hose to the helmet a finger should be inserted into the elbow pipe on the latter and the inlet valve lifted, so as to see that it is free on its seating and that the spring is working properly.

186. *Testing air hose.*—The lengths of air hose that are to be used should always be tested to a pressure considerably higher than that of the depth of water to which the diver is going. A flow or leak in the air hose may be detected by passing the bight through water and watching for escape of bubbles of air.

187. *Testing telephones.*—Much inconvenience will be avoided if the telephones are tested and their proper functioning assured before the diver is dressed. It is very trying to the diver and all concerned to find that at the last minute the telephone is out of order.

188. *Testing escape valve on helmet.*—If neglected, the escape valve, due to corrosion, will sometimes stick and fail to function properly. As a precaution it should always be tested before the diver descends under water. Pressing in on the push button on the inside of the helmet and suddenly letting it go will indicate whether or not the valve will function. A case is known where the escape valve was removed for the purpose of making a repair. The valve body cover was screwed in place to prevent it from being lost. For some reason the valve was not replaced, and a diver attempted to use the helmet with the result that he was unable to regulate his air. An inspection or test would have saved much time, trouble, and the confidence of an inexperienced diver.

189. *Divers attendants.*—Each diver while under water requires an attendant to hold the life line, and an assistant for the air hose when the diver is coming up or going down. Other men should be stationed to see that the hose and line pay out clear and also to coil them

down when required. The post of attendant is a very responsible one, and a qualified diver should always, if possible, be employed for this duty. From the time the diver gets on the ladder to go down till he comes up again the attendant must concentrate his mind on his charge and never let his attention wander. The life line and air hose must be held clear of the gunwale and moderately taut, so that the movements of the diver can be felt and a rough idea formed of what he is doing. But care should be taken not to have them so taut so as to inconvenience the diver. The attendant must constantly glance at the gauge to look out for changes in depth, and he must always know whereabouts the bubbles are coming up and the direction in which they are moving. Where there is much rise and fall of tide he must see that the descending line is frequently hauled in or lowered so as to keep the weight on the bottom and the line taut. When the diver is working on a ship's bottom or other place from which he might fall, the attendant must be on the alert to catch him with the life line and hose should this happen, and should the life line be paid out for any reason, such as sending down a rope or a slate, he must see that the air hose is kept well taut in case of a similar accident. When two or more divers are down together, the attendants should do all they can to prevent them getting foul of each other, watching the two sets of bubbles and warning the men by telephone if necessary.

190. *Indications of the gauge.*—Great attention must be paid to the gauge. Should it fall quickly, it shows that either the diver is coming up or something is wrong with the apparatus; the signal should be at once made to the diver asking if he is all right. If he replies that he is coming up, the hose and life line must be gathered in smartly. Should, however, the diver signal back "All right" and the gauge continues to fall, something must be wrong with the apparatus, and the diver must be at once called up. If the gauge rises quickly, it shows that the diver has fallen; ask if the diver is all right. If he signals "All right," he has recovered himself; if no reply is received, he must at once be hauled to the surface, but not too rapidly. If the diver has any difficulty in getting under water or should be blown up from the bottom, the attendant must use his discretion and ask the officer's permission to ease or stop the pump until the surplus air has been gotten rid of. If the diver can not help himself, the valve and tap on the helmet must be opened or the cuff pulled open so as to let the excess air escape. Be careful to have the hose and line well in hand so that the diver can not drop down suddenly.

If the diver on coming up has a number of turns round the descending line and it is difficult to take up the slack of the air hose and life line, it is best to pull up the descending line, air hose, and life line together.

191. *Notes on signals.*—The following instructions, copied from the Manual for Divers (1905), are those in general use in the Navy and are incomplete:

> The life line and the air hose provided with the apparatus are the means generally used in the service for making signals and are found quite sufficient for all requirements. The following is the code adopted at the torpedo station in the instruction of seamen qualifying as seamen gunners. The important point to observe is that the diver and tender have a thorough understanding of the signals to be used.

ON THE LIFE LINE.

Pulls.	By diver.	By tender.
One	Am all right	Are you all right?
Two	Ease me down	I will ease you down.
Three	Pull me up	Come up; or, I will pull you up.

ON THE AIR HOSE.

One	More air	Answer by one pull on life line (I will comply).
Two	Less air	Answer by two pulls on life line (I will comply).

Two pulls of the life line and two on the air hose, in rapid succession, indicates that the diver is foul and can not free himself. On receiving this signal no attempt should be made to haul him up, but his signal should be answered and another diver sent down to release him.

Never arrange a code of signals for carrying on work that involves any of the established signals on the life line, as it is a dangerous experiment and may lead to serious misunderstanding.

The following are the British Admiralty instructions in regard to signals for divers—

Signals from attendant to divers.

DIRECTION SIGNALS.

On air pipe:

1 pull means	Search (or remain) where you are.
2 pulls mean	Go straight ahead.
3 pulls mean	Go to the right.
4 pulls mean	Go to the left.

The right and left signals are in future to be obeyed in the following way: On receiving three pulls the diver is to face his own shot rope or whatever corresponds to it and then move to his own right. On getting four pulls he is to face his shot rope and then go to the left.

On breast rope:

1 pull means	Are you all right?
2 pulls mean	Am sending a slate.
3 pulls mean	You have come up too far, go down till we stop you.
4 pulls mean	Come up.

A rapid succession of pulls on the breast rope or air pipe is the telephone call used with the old pattern gear or when the call bell is out of order.

Foul signals can be made on either breast rope or air pipe (whichever is clear). "Two bells" repeated several times quickly means that the diver is fouled and requires the assistance of another diver. Three bells repeated several times quickly mean that the diver is foul, but can clear himself if left alone.

NOTES ON SIGNALS.

All signals made and received, and all sudden movements of the diver, or anything that seems to show that he is in difficulties are to be reported to the officer in charge. The person receiving a signal in this way, unless you clearly understand it, should never answer. The signal, when understood, should be repeated to the diver to show him that it has been received; if you get a wrong signal, or none at all, go on making the signal until it is correctly answered.

The attendant must ask the diver if he is all right from time to time and if no reply can be obtained the diver must be hauled up under the direction of the officer in charge.

If the breast rope and pipe get turned round the shot rope it may become impossible to get signals on a slack rope, and the turns must be taken out from the boat as soon as they are noticed. Do not try to make signals on a slack rope, but pull up a foot or two till the diver can be felt, and then make the signals gently but distinctly. A sudden or violent jerk may, by striking the helmet up against the diver's head, cause him serious injury.

Remember that a diver at work may sometimes be in such a position that he can not answer your signals for several seconds so allow him a reasonable time before you repeat it.

Holding the breast rope and pipe.—In attending the pipe or rope give the diver two or three feet of slack when he is at the bottom, but just feel the weight of the man from time to time to make sure that you have not got too much slack out. It is extremely embarrassing for a diver to find his pipe and rope too taut, so that his head is being continually pulled away from his work. As it is difficult for him (without the telephone) to make his attendants understand that they are holding him too tightly, special care must be taken that this does not happen.

Interpreting signals.—Judgment must be used in interpreting signals and the attendant must consider what they are most likely to refer to. For instance, suppose a diver is going down and you are his attendant and holding the breast rope. You should know from the gauge when he gets close to the bottom, and if you get one pull about that time it means of course that he has reached the ground, but if you were to get one pull while the gauge showed that the diver had not yet reached the bottom the meaning would be, hold on, the diver has probably let go the shot rope, or for some reason is unable to stop himself and wants to be held by the pipe or breast rope. If you get two bells immediately after the diver has signalled that he has reached the bottom the meaning would be that he wanted you to pull up the shot rope (which is probably too slack). When it was properly adjusted he would (hold on) when you would turn it up.

Two bells immediately after the diver has signaled that he is coming up mean that he wants to be pulled up; do this very gradually. If there was anything seriously wrong, the diver would have signaled to be hauled up with four pulls on the air pipe.

On going down, before a diver leaves the surface he will signal by waving his hand that he is ready to do so. The attendant answers this signal by one pull of the breast rope. The diver must not be allowed to go down the shot rope until he has made this signal.

Four pulls on the air pipe is an emergency signal and the diver must never use it unless something serious has happened. There must be no delay in obeying it.

Signaling when air pipe and breast rope are seized together.—Pipe and rope are sometimes made into one line by seizings, so as to lessen the risk of fouling when diving on a sunken wreck. It is then only possible to make a limited number of signals, and a special code must be devised according to the circumstances of the case and the nature of the work in hand, leaving out the signals which are least likely to be wanted. The following system of signals is inserted as a guide:

FROM DIVER.

On breast rope and air pipe together:

1 pull means	I am all right.
2 pulls mean	Send me a slate.
3 pulls mean	Send me a rope.
4 pulls mean	I am coming up.

FROM ATTENDANT.

1 pull means	Are you all right (when diver is ascending one pull stop).
2 pulls mean	Look out for rope or slate which we are now lowering.
3 pulls mean	You have come up too far. Go down slowly till we stop you.
4 pulls mean	Come up.

The signals for "pull up," "lower," and "hang on" would be the same as usual except that they would have to be made on the pipe and rope together.

192. In view of the superiority of the British Admiralty signals for divers and the incompleteness of the code in use it is recommended that the Navy Code of Signals for Divers be modified and extended to include a system of signals that will render communication in connection with the employment of divers practicable under various conditions of under-water work, the modified code of signals and the instructions for their use to be included in a revised edition of the Manual for Divers.

193. *The diving manual.*—For information there is forwarded herewith inclosure (W), a copy of the Navy Diving Manual, 1905. By comparing this edition with that of the British Admiralty Diving Manual, 1910 (on file in the Office of Naval Intelligence), it will be noted that the former is very incomplete, and a new edition of the diving manual, corrected up to date, should be published for the information and guidance of naval service.

194. *Duties of officers.*—The efficiency of diving operations, diving apparatus, and divers depends, primarily, upon their intelligent supervision. In the past definite personal responsibility has been nonexistent, with consequent lack of efficiency. To insure the carrying out of a systematic routine in the care, preservation, and maintenance of diving apparatus, the proper supervision over the instruction and employment of divers, and the efficient conduct of diving operations it is essential that personal responsibility be definitely

placed. This, of course, is a matter that should receive the attention of a board of officers, appointed for the specific purpose. However, it is my opinion that the purchase, repair, etc., of diving apparatus should remain under the cognizance of the Bureau of Construction and Repair, and that all other questions relating to diving should come under the direction of the Bureau of Ordnance. On board ship the gunnery officer, assisted by the torpedo officer and the ordnance gunner, should be directly responsible for all matters relating to diving. For the purpose of improving the efficiency of naval divers and diving operations and as an assistant to the Chief of the Bureau of Ordnance an officer of suitable rank should be appointed as an inspector of diving, with duties and powers similar to those of the inspector of diving in the British Navy. The health of the divers should be under the supervision of the Bureau of Medicine and Surgery.

195. *Duties of the inspector of diving.*—He shall have as his assistants such officers and enlisted men as may be deemed necessary from time to time, including the officer in charge of the School for Divers and his assistants. He shall keep the records of diving operations, diving apparatus, and divers; shall cause all necessary reports to be made to him, and shall submit reports to the various offices, bureaus, and divisions of the Navy Department. He will issue instructions as may be necessary for the proper conduct of diving operations on board ships and at shore stations; for the instructions of the officers and men in the art of diving; and for the care, preservation, maintenance, and upkeep of diving apparatus. He will make or cause to be made, from time to time, as may be necessary to insure efficiency, inspections of the diving apparatus on board ships and shore stations. At such inspections he will investigate, or cause to be investigated, the efficiency of the divers and the methods employed by them. He shall prepare the necessary detailed specifications for the manufacture, purchase, inspection, and tests of diving apparatus. He shall prepare the allowance lists for the issue of diving apparatus, and, as often as may prove necessary, shall make corrections and additions to the Manual for Divers. He shall furnish the necessary data for corrections or additions to the Naval Regulations and Instructions. To be eligible for the appointment as inspector of diving an officer should possess special qualifications as a diver and a thorough knowledge of all kinds of underwater work.

196. *Duties of gunnery officers in connection with diving.*—It is not necessary that the gunnery officer be a qualified diver, but he should familiarize himself with every detail of the diving apparatus, the methods of its employment, and the requirements of divers. He shall have the authority to delegate either the torpedo officer, ordnance gunner, or torpedo gunner, or all of them, for such duties

in connection with diving as he may deem proper, providing that they are or have been qualified divers. Torpedo officers should be encouraged but not required to become qualified divers. All ordnance and torpedo gunners should be required to attend a course at the school for divers for the purpose of learning how to properly manage and conduct diving operations. It should be a requirement that all candidates for appointment to the grade of ordnance or torpedo gunners must be qualified divers, or shall have been qualified divers at one time or another, and that at the time of the examination for appointment they shall be perfectly familiar with the Naval Regulations and Instructions relating to diving and also with the contents of the Manual for Divers. Whenever practicable a qualified officer should be placed in charge of diving operations. If not practicable to assign an officer for this duty it should be delegated to the highest ranking competent and qualified enlisted man. The officer should be held accountable for the care, preservation, and maintenance of diving apparatus, the instruction and employment of divers, and the conduct of diving operations.

197. *Officer's duty in connection with fitting out diving boat.*—Besides the special equipment for the particular work to be done the officer in charge should see that the diving boat or boats contain the following:

COMPLETE DIVING OUTFIT FOR TWO DIVERS.

Red flag and staff.
Lead line.
Boat's anchor and cable.
Boat's compass.
Hand flags for singaling.
A watch for timing the diver.
Binoculars.
Chart of location.
Sextant or stadimeter for measuring angles or distances.
Long heaving line.
Large shackle.
Coil of small stuff for lashings.
Coil of rope for sending down to a diver.
Emergency medical outfit.
Slate and pencil for making sketches under water.
Sufficient men to manage the boats while the divers are down independent of the pumping crew and attendants.

198. *Duties of officers in connection with diving operations.*—The officer will be responsible for the arrangement of the diving apparatus and the adequacy of the air supply; he will see that the diver is properly dressed and that the air hose is correctly joined up, the oil cocks on top of the cylinders closed, and the pump secured. Whenever the diver is down the red flag to be prominently shown. He must explain to the diver exactly what has to be done and see that he

understands the routine to be followed in coming up, especially that to be followed in deep diving. All times are to be taken by watch and recorded, any change of depth must also be noted and the gauges read and logged every few minutes when the diver is working in deep water, as a slight change in depth is likely to make a difference in times required for coming up. He will keep a diving log and cause to be entered in it any data relating to diving operations, apparatus, or divers. The following example page from a diving officer's notebook shows the proper way of logging a dive, everything being, of course, written in at the time it happens and not from memory:

May 22.

Diver (name), (rate).

Depth .... Remarks.
Left surface..............................
Arrived at bottom.......................
Depth by gauge ....
Do..................
Do....................
Do..................
Do..................
Called up................................
Left bottom..............................
Reached 30 feet.........................
Left 30 feet..............................
Left 20 feet..............................
Left 10 feet..............................

An officer to be eligible to take charge of diving operations should have passed through the diving course. It is immaterial as to whether the officer is a qualified diver or not, but in all cases he must be familiar with the training and requirements of divers. He must thoroughly understand the management of divers and diving operations and must be conversant with the diving manual.

199. *Working on a ship's bottom.*—When work is to be done about a ship's bottom, propellers, etc., the officer will superintend the rigging of all stages, bottom lines, or ladders that may be required for the work, and will be responsible for their security. He is also responsible that the engine-room department is warned whenever a diver is going down to the neighborhood of the propellers, valves, or submerged torpedo tubes. While at such work every possible precaution should be taken to prevent the diver falling. The boat must be kept carefully abreast of him and the air hose and life line carefully attended; on no account must the diver be allowed to go under the keel of the ship and up on the opposite side of her to that alongside which the boat is lying.

200. *Joining up two pumps to one diver.*—To join up two or more pumps to one diver the manifold junction inclosure (X) is employed. The left-hand delivery nozzle of each pump is connected to one of the arms of the junction by a length of hose. It is better to use short lengths with a double female connection and keep the 50-foot lengths for the diver. The diver's hose is joined up to the arm of the junction, which has no tap. If only two pumps are connected up, the tap on the fourth arm is kept shut, the other being open. Before connecting the air hose to the diver's helmet its end is blocked and both pumps are hove round till the full pressure is reached; this is to test the connections. This junction pipe should be mounted on a board and securely lashed to some convenient place where it is impossible for the taps to be accidentally disturbed. In sending the diver down, the second pump should not be started until the man has left the surface. In coming up one pump will generally be enough after the diver has reached his first stopping place. In joining up extra pumps or taking them off, the greatest caution must be exercised in opening taps on the junction when a diver is down, as should the air be allowed to escape the diver would be instantly killed if his inlet valve failed to act. On no account whatever may the hose of two divers be joined up to the same junction when using hand pumps.

201. *Management of the diver's ascent.*—When the diver is ready to come up the officer himself, or a reliable person detailed by him, attends at the gauge with watch and notebook for the purpose of controlling the pumps and stopping the diver. He is to look inside the pump lid for the error of the gauge and informs the attendant where the diver is to stop by ordering, "Bring the diver up to 30 feet," as the case may be. The gauge is watched carefully while the diver comes up; as soon as he is nicely on the move the extra pumps may be stopped, but if there is a strong tide or other hindrance give the diver plenty of air up to the last minute. If he is coming up too quickly stop the pumps and check him at once; after giving this hint he may be allowed to come on again slowly. When he is 30 feet below the first stopping place stop the last pump and tap the gauge continuously with the fingers. This to prevent it showing too high or being sluggish; when the needle is just coming on to the proper depth (allowing for gauge error) order "check the diver." This is done by the attendant giving one pull on the air pipe. Start the pump again, log the time, see that the marks on the life line correspond (roughly) with the gauge and then stop the pump again to get a second reading of the gauge. The attendant assists the officer at the gauge in this way: Suppose the diver is to be stopped at 20 feet. The attendant looks out for the 20-foot

mark on the life line as he is taking it in, and if he sees it appear at the surface before the officer at the gauges calls out, he is to stop the diver immediately without waiting for order and report that he has done so. This is not to take the place of the gauge method, but only to check it. In a tideway the gauge alone must be relied on. When it is time for the diver to come up to the next stopping place, call him up, stop the pump as soon as he answers and proceed as before. If the diver overshoots the mark and comes too high, send him down at once by signal; the pump must be restarted before he begins to descend or he may get squeezed.

202. *Diving apparatus in case of fire.*—The diving gear provides a good safe, smoke helmet for use in fires, or in bunkers, etc., where poisonous gases may have accumulated. A jumper should be made, fitted at the neck to take over the studs of the breastplate, and at the bottom and cuffs, fitted with strings to the jumper close to the body and wrists. The jumper should be kept in a convenient place near the air pump, with the helmet and air hose screwed on. In case of fire a diver could put on the jumper and proceed to the fire, other men following with the pump and placing it in position; the air hose from the helmet is screwed on to the pump on the "left," with the pump at "one diver, deep water," when, with two men to heave round, the man would get a plentiful supply of air. The man should, of course, wear shoes and his outer clothes should be wetted.

203. *Diving apparatus in case of collision.*—The practice of rushing a diver to the scene of a collision should be discontinued. Nothing at the instant of collision could be accomplished by the diver to affect the safety of a vessel, and to send him down under the ship at such a time would endanger his life. The diving apparatus can be made ready at leisure and the diver sent overboard when his services become necessary. Dressing diver in record time on deck and keeping him standing or running around with a heavy apparatus on is of no benefit and a hardship on the diver. He would most likely become exhausted before he could go under water. It is a waste of time to try to work a diver over the side or under a ship's bottom without first rigging up a proper system of stages, ladders, or lines for him to hold on to and to protect him from a fall.

204. *General recommendations.*—In view of the inefficiency of naval divers, the general lack of information relating to the subject of diving, an improper method of training divers, and the nonexistence of definite instructions and regulations for the care and preservation of diving apparatus, and for the conduct of diving operations, it is necessary that the whole subject and status of diving in the Navy be revised in a broad and comprehensive manner if it is to be improved

and modernized in accordance with the best practice of the art of diving and the requirements of military efficiency. Within recent years similar improvements have been effected in all the leading European navies, principally in British Navy, and at the present moment European divers are so much superior to those in this country as to admit of no comparison. As a result of the deep-diving tests it is apparent that a change from present methods is necessary, if only for humanitarian reasons.

205. At the present time our divers work under conditions that are dangerous, and needlessly so. General inefficiency exists as the result of ignorance and can only be corrected by proper training. The deep-diving tests have clearly demonstrated that great improvements in methods and apparatus are quite feasible.

206. In order that the greatest good may be derived from the results of these tests, and will directly follow important improvements in diving apparatus, the following recommendations are submitted for approval:

I. It is recommended that a board of officers be appointed to consider and suggest ways and means for improving the efficiency of naval divers, the methods of training officers and men in the art of diving, the organization of an efficient school for divers, and for the purpose of providing for the needs of the Navy in regard to all other matters relating to diving.

II. It is recommended that the board enter into the subject in detail and submit a report containing all necessary recommendations for carrying into effect the results of its findings.

III. It is recommended that, in addition to other details that may appear necessary, the board consider and report on the following:

(*a*) The organization of a school and the methods for training naval divers.

(*b*) The course of instruction in diving for officers.

(*c*) The qualifications for divers.

(*d*) The course of instruction for enlisted men.

(*e*) What officers and men shall receive instructions.

(*f*) The issue of instructions for governing the carrying on diving operations.

(*g*) The necessity for and the continuance of gathering and pubishing useful data in regard to the most efficient manner of conducting diving operations.

(*h*) The disqualification and requalification of present qualified divers and the qualification of candidates for the class in diving.

(*i*) Causing all divers to requalify periodically.

(*j*) The pay and extra compensation for divers.

(*k*) The appointment of an officer as an inspector of diving.

(*l*) The fixing of definite personal responsibility for the conduct of diving operations, the care, preservation, maintenance, inspection, and use of diving apparatus.

(*m*) Increasing the efficiency of the system of diving in the Navy in all its branches.

(*n*) Including in the courses of instructions for officers and men in gunnery and torpedoes a course of instruction at the school for divers.

(*o*) Including in the qualifications of applicants for promotion to the grades of ordnance and torpedo gunners the requirement that they be or have been qualified divers and that they are competent to take charge of important diving operations.

(*p*) The treatment of various diseases as the result of diving.

(*q*) The composition of outfits of diving apparatus for various purposes.

(*r*) The qualification as divers of all members of the crews of submarines.

(*s*) The qualification as divers of carpenter's mates, ship fitters, and special mechanics, in addition to gunner's mates.

(*t*) The construction and provision of special apparatus for increasing the efficiency of diving operations.

(*u*) That all candidates for instruction in the school for divers be proficient in the art of swimming.

(*v*) The physical requirements of applicants for the course in diving.

(*w*) The course of training and periodical exercise with mine-rescue apparatus. The care, preservation, and upkeep of mine-rescue apparatus.

(*x*) The adoption of a suitable form of submarine-escape apparatus. Methods of training and exercise with submarine-escape apparatus. Care, preservation, and upkeep of submarine-escape apparatus.

(*y*) The provision of all necessary apparatus and equipment for the training of divers and submarine crews at the school for divers.

IV. It is further recommended that a new and up-to-date edition of the Manual for Divers be prepared, published, and issued to the naval service as in the case of other service books of instruction.

V. It is recommended that the purchase, issue, and use of the "crinoline" or "shackle" as an article of diving apparatus be discontinued.

VI. It is recommended that the purchase and issue of the following articles of diving apparatus be discontinued: Wristlets, woolen; caps, woolen; dresses, canvas, overall; neckerchiefs, cotton; signal lines, manila, 120 feet; frames, screw, for helmet; rubber diving mittens, with rings and clamps; shackles or crinoline mittens, woolen; spanners, helmet bolts; and helmet, bolt type.

NOTE.—Certain articles of an improved type to replace certain of the above will be included in the new specifications that are now being prepared.

VII. It is recommended that purchase of telephone outfits for diving apparatus be discontinued until the specifications for same have been revised.

VIII. It is recommended that the present classes for instruction in diving be discontinued, for the reason that the course of instruction is incomplete, the information imparted to the pupils is generally erroneous, the methods of instruction are obsolete, the divers qualified are generally inefficient, and for the additional reason that they do not accomplish the purpose for which they are intended.

IX. It is recommended that a school of instruction for divers be established and furnished with the necessary apparatus, appliances, paraphernalia, equipment, and accommodations for the instruction of officers and men in diving, submarine escape, and rescue work in irrespirable atmosphere in accordance with the needs of the Navy as may be decided by a special board of officers appointed for the purpose.

X. It is recommended that the courses of instruction in diving be as follows:

(*a*) *Officers, gunnery and torpedo* (*7 to 14 days*).—To include testing of pumps and gear, rigging diver's stages, methods of doing work, and management of diver's ascent from deep water. To dive in various depths as convenient and to perform practical work under water and to obtain a thorough knowledge of signals. Officer medically unfit not to go underwater, but to be thoroughly instructed in the management of divers and apparatus.

(*b*) *Ordnance and torpedo gunners and chief gunners requalifying* (*7 to 14 days*).—To be thoroughly instructed in the management of divers and apparatus and to practice bringing divers up from deep water.

(*c*) *Petty officers for ordnance and torpedo gunners* (*7 to 14 days*).—The same as for gunners and to dive as may be convenient.

(*d*) *Seamen divers* (*60 days*); *artificer divers* (*60 days*); *divers requalifying* (*14 days*).—To include thorough instructions in the physics and physiology of diving, first aid to the diver, every detail of the apparatus, diving at all depths, diving at 15 fathoms and above on three occasions in the case of seamen and artificer divers requalifying, and on 10 occasions in the case of divers qualifying. On each of the above occasions must manage the ascent of some other diver. They must be familiar with the contents of the diving manual, and are to be competent to take charge of and manage the ascent of a diver from deep water in accordance with the tables provided. They are to have practice at practical work of various kinds and special instructions in the handling of lines, stages, etc., underwater. Artificer divers to have special instructions in the handling of pneumatic and other tools, patching holes, trimming plates, fitting cofferdams, clearing choked valves, and other practical mechanical work, and the making of sketches under water.

XI. It is recommended that a certificate of qualification as a diver be continued in force during the current enlistment of the man to whom it is issued and be surrendered upon the receipt of a discharge from the naval service. Desirable men wishing to requalify should be afforded an opportunity to do so upon reenlistment. Men over 45 years of age not to be requalified. An applicant diver to forward an official application bearing an indorsement from his medical officer that he is physically qualified.

XII. It is recommended that the physical qualifications for a diver be as follows:

He must be fit to stand the strain, of average height, not obese, steady, of good habits, free from heart and lung troubles; must have no derangement or disease of the kidneys, or degeneration of the arteries, or any constitutional disease; must not be addicted to the use of alcoholic liquors nor to the use of tobacco in excess. In view of the necessity for the equalization of pressure within and without the tympanic membrane, there must be no middle ear disease or catarrhal condition that can interfere with the patulousness of the Eustachian tubes.

XIII. It is recommended that the rates of pay and extra compensation for divers be revised in accordance with the following:

(*a*) Add to article 4427, United States Navy Regulations, 1913, a paragraph stating, substantially, as follows:

> Enlisted men who have successfully completed a prescribed course of instruction for divers of either the seamen or artificer branches may be given by the Bureau of Navigation a certificate to that effect, which shall entitle them to receive $2 per month in addition to the pay of their rating in which they are serving, such certificates to continue in force only during the enlistments in which they are graduated; such certificates to be canceled unless renewed by requalifications after reenlistment for four years within four months from date of honorable discharge.

(*b*) Add to article 4427, United States Navy Regulations, 1913, a paragraph stating, substantially, as follows:

> Chief petty officers detailed as instructors of divers at the school for divers who qualify for instructors by examination shall receive hereafter, in addition to their pay, the sum of $10 per month while so detailed, such pay to be considered extra pay for special duty. Chief petty officers must be citizens of the United States, serving under continuous service, and qualified divers in order to be eligible for examination for detail as instructors of divers at the school for divers. They must also qualify in accordance with the requirements prescribed by the Bureau of Navigation.

(*c*) Paragraph 33, article 4427, United States Navy Regulations, 1913, to be changed to read:

> Enlisted men of the Navy not under instruction at the school for divers shall when employed in submarine diving receive extra compensation therefor, to be charged to the bureau for which the service is performed, at the rates set forth in the following scale:

Scale of extra compensation for divers.

Class of work and circumstances in which extra compensation may be paid.	Designation.	Depth in fathoms.		Time under water.	
		From—	Up to and including—	For first hour or fraction.	For each subsequent half hour or fraction.
While actually employed in diving if not paid a bonus or gratuity for special work in connection with such employment.	Diver.....	1	6	$2.00	$0.50
		6	12	3.00	1.00
		12	20	4.00	2.00
		20	25	5.00	3.00
			Over 25	10.00	4.00
While actually employed in diving for practice or for the instruction of other divers (not diving school).	...do......	1	12	1.00	.25
		12	20	2.00	.50
		20	30	3.00	1.00
			Over 30	5.00	2.00
While actually employed as an attendant on divers under water.	Attendant	....	....	50 cents per hour. This payment to be made to the actual attendant and not to the officer in charge of the party.	

NOTE.—Period for which payment is made is to count from the time of entering the water to time of leaving the water, and should it be subsequently found that the work was improperly done, the commanding officer, at his discretion, may cancel the whole or any portion of the payment. Only one first-hour rate is to be paid for any one day, but in cases of diving at two different depths payment may be made at whichever first-hour rate is more advantageous to the diver.

(*d*) Add to article 4427, United States Navy Regulations, 1913, a paragraph, stating, substantially, as follows:

Artificer divers, when actually employed under water on a purely mechanical piece of work which the ordinary diver is not capable of efficiently performing, and when not paid a bonus, or gratuity, are to be paid a half day's pay of the substantive rating for every hour and proportionately for parts of an hour in addition to the extra compensation to which they may be entitled according to the scale of extra compensation to be paid to divers for work under water.

(*e*) Add to article 4427, United States Navy Regulations, 1913, a paragraph stating, substantially, as follows:

For the recovery of articles under water, a bonus not exceeding $20 nor one-fourth of the value of the article, may be paid to the diver employed in the recovery, in lieu of payment of extra compensation by scale, of which bonus one-tenth is to be paid to the attendant. In case more than one diver is employed in the recovery the payment of the bonus to be divided equally between the divers after deducting one-tenth for the attendant. Should payment by scale be more advantageous to the diver or divers, payment may be made by the scale of extra compensation for the payment of divers.

(*f*) Add to article 4427, United States Navy Regulations, 1913, a paragraph stating, substantially, as follows:

A gratuity not exceeding $50 may be paid to a diver in lieu of payment by scale of extra compensation for divers, in exceptional circumstances requiring dispatch and important skilled work satisfactorily performed, of which one-eighth is to be paid to the attendant.

(*g*) Add to article 4427, United States Navy Regulations, 1913, a paragraph stating, substantially, as follows:

Enlisted men loaned to another vessel of the Navy and employed diving are entitled to and shall receive extra compensation in accordance with the regulations for the pay of divers. Enlisted men of the Navy loaned to other branches of the Government service and employed diving are entitled to and shall receive extra compensation at the Navy rates. Enlisted men of the Navy loaned to a private or commercial organization and employed diving shall be entitled to, and shall receive from such private or commercial organization, extra compensation at double the Navy rates.

XIV. It is recommended that a diver who fails to conform to conditions of exercise, or is at any time unwilling to dive, be liable to deprivation of his diver's certificate and $2 per month for the current quarter.

XV. It is recommended that gunner's mates, carpenter's mates, ship-fitters, and other special mechanics, showing the necessary aptitude and possessing the physical qualifications, be recommended for and detailed for a course of instruction in diving, at the school for divers, upon reenlistment under continuous service.

XVI. It is recommended that all candidates for the course of instruction at the school for divers be proficient in the art of swimming.

XVII. It is recommended that all members of the crews of submarines be instructed in diving, as far as relates to the descent and ascent of a diver under water.

XVIII. It is recommended that a number of recompression chambers, for the treatment of caisson disease, be constructed, furnished with the necessary equipment, and retained ready for use at suitable stations. That when time and circumstances permit, a recompression chamber be obtained and used in connection with deep-diving operations.

XIX. It is recommended that a suitable vessel, equipped for deep diving at sea, be maintained at the school for divers, kept in readiness for important and distant deep-diving operations, and given employment upon appropriate occasions.

XX. It is recommended that an inclosed steel experimental diving tank, fitted with glass observation windows, necessary connections, etc., be provided for use at the school for divers.

XXI. It is recommended that, whenever practicable, a suitable diving compartment be required in the construction of new submarine vessels, for the reason that it appears that the ability of a submarine to maneuver along the bottom of a waterway, and to send out divers would be especially valuable in the placing and removal of submarine obstructions, cables, mines, countermines, etc. It would also be an advantage to the commander of a submarine when maneuvering in this manner and running into an obstruction to submarine navigation to be able to send out divers to investigate and report the nature of the obstruction and the means of avoiding it without the necessity of rising to the surface and being forced to show his periscope abovewater or to disclose his identity at an inopportune moment. The possibilities and military value of such service are apparent. The lack of such facilities by the British submarine flotilla at the present moment evidently renders the position of the German battle fleet secure.

XXII. It is recommended that the ordnance gunner, or in his absence the torpedo gunner, be always placed in charge of the diving party of the vessel to which he is assigned, providing he is qualified as previously recommended, and that all diving operations be carried out under the direction of the gunnery officer, or in his absence the torpedo officer, except in vessels not carrying all or any of the abovementioned officers, when the place of the gunner in charge of the diving party may be taken by another specially qualified warrant or chief petty officer and the duty of superintending the diving party by some other commissioned officer.

XXIII. It is recommended that when diving operations are being carried on, all the seamen and artificer divers are to attend if possible.

XXIV. It is recommended that, at least once a quarter, and oftener if favorable opportunities present themselves, all seamen and artificer divers on all vessels of the Navy be required to put on the diving dress and to exercise under water, and that each man be given a definite task to accomplish. Practice diving to take place in 12 fathoms of water at least, if practicable. When two or more ships having only one pump each on board are in company and conditions are favorable, two pumps are to be connected together by means of the four-way junction piece or manifold and diving exercises carried out in depths of water greater than 12 fathoms.

XXV. It is recommended that the gunnery officer with the assistance of the ordnance gunner and the divers, inspect all the diving apparatus once a quarter, and that the condition in which it is found be reported in the proper returns.

XXVI. It is recommended that reports be required from all officers placed in charge of diving operations, stating, specifically, the nature and extent of all diving operations carried out under their supervision, a description of the methods by which they were executed, and other useful or interesting information relating thereto. That these reports be classified and filed for reference. That accounts of important diving operations be published in circular form for the information and consideration of all officers and men interested in diving.

XXVII. It is recommended that all divers be examined by the medical officer of the ship on which they may be serving once in each year to ascertain that they are physically capable of working under water and that if any are found unfit they will be deprived of their certificates of qualification as divers. That reports be made of the nature, extent, treatment, etc., of diseases, sickness, etc., as a result of diving and occurring within the range of the observations of individual medical officers.

XXIX. It is recommended that the methods and apparatus for conducting diving operations be continually studied and that an attempt be made to take advantage of improvements and scientific research relating to work under water for the purpose of maintainng an efficient corps of divers in the Navy.

207. There are forwarded herewith inclosure (Y), the copy of a personal letter sent to, and the answers received from, various gunners and chief gunners in the Navy relative to the subject of diving and diving apparatus. These letters are interesting principally because they indicate graphically the lack of expert knowledge in regard to the art of diving on the parts of those who are usually placed in charge of all diving operations; the entire lack of uniformity of methods in the conduct of diving operations; wide divergence of opinions as to the proper construction and employment of diving apparatus; and for the additional reason that the descriptions of accidents and hardships suffered by divers show the urgent necessity for a general improvement of all the conditions relating to the art and practice of diving in the Navy.

Since this report was written a short series of diving tests were carried out in Long Island Sound from the U. S. S. *Walke.* Owing to unfavorable surface and tidal conditions the tests were limited to brief exposures to high pressures. (See Appendix 2 for report.)

208. Sufficient information was obtained, however, to determine the practical and mechanical arrangements necessary for successful operation of the compressed air method of diving. The primary requirement is to insure an adequate air supply for the divers. In this connection 5 cubic feet per minute, measured at the depth the diver is under water, may be safely assumed to be the maximum air supply required by a diver. Thus $\frac{200}{33}$ feet × 5 equals the maximum volume of air per minute that the compressor must take in to supply a diver at a depth of 200 feet. If the diver were being furnished air from a torpedo air flask it is important to know how long the supply within the flask will last him. The following formula serves as a means for determining the duration of the air supply for a diver at any depth receiving air from a high pressure air flask of any capacity:

$$\frac{\text{Capacity of flask in cubic feet.} \times \text{Atmospheres of pressure within flask.}}{5\text{ cubic feet} \times \frac{\text{Depth of sea water in feet.}}{33}} =$$

maximum duration of air supply for one diver in minutes.

The 5 cubic feet per minute takes into account the losses due to friction and changes in temperature. It must be remembered that an air flask can never be exhausted by a diver as a greater pressure must be maintained within the flask than that in which the diver is working in order to maintain a circulation of air within the helmet. The difference in pressure required depends upon the sizes and lengths of piping between the source of supply and the diver. It has been found that a 25-pound per square inch pressure head will suffice for ventilation purposes at any depth. This 25 pounds to be measured as near the helmet as possible. The diver should be familiar with his own air requirements, and if he signals for more air the pressure shown on the surface gauge should be increased accordingly. The operation is very simple and but few adjustments are necessary. During all dives mentioned in the report previously referred to, only one adjustment was made to the air supply and this was necessary only because the loss due to friction in a long length of air hose had not been taken into consideration. It is estimated that a 21-inch torpedo air flask will contain sufficient air to last a diver 30 minutes in 198 feet of water. Two flasks would last two divers the same length of time or one diver for one hour, etc.

209. In all diving operations of any character whatever, it is a wise plan to secure a reserve air supply equivalent to one-third of what is actually required. Thus, for instance, if it is calculated that a 21-inch torpedo air flask will contain sufficient air to last the diver 30 minutes, one-third of the supply should be kept in reserve for an emergency and the diver should count on its being sufficient for only 20 minutes. The same precaution should be taken when using hand or power driven diving pumps. It is readily apparent that if a diver is permitted to work close to the limit of his air supply and anything goes wrong he will immediately find himself in a precarious situation. It may also be noted that divers in the Navy commonly disregard this precaution and that it is the cause of many accidents. A definite reason why a reserve air supply is necessary is because a diver's consumption of oxygen and production of CO_2 will greatly increase with hard work. If he should descend to the limit of depth possible with the air supply at hand and become fouled or meet with an accident of any kind the natural tendency for him is to struggle out of the tangle. Then if his air supply is not adequate to his increased exertions he will suffer severely from improper ventilation of his helmet, whereas, if the pump could be speeded up or the setting of his reducing valve be altered there is nothing to be feared at the moment. If it is then seen that a diver is in trouble there remains a period of time during which relief measures may be adapted.

210. During the tests at sea it developed that when a descending line weight refuses to remain on the bottom, due to the effects of the tide, it is impracticable to dive. Enough weight should be added so the line will sink and the weight will remain stationary. If a diver

is down and he finds that the descending line weight is being dragged along the bottom and away from his work he should know that the diving vessel is swinging to a change of wind or tide and that it is dangerous for him to remain on the bottom. It is most important that a diver should not be under water when the diving vessel is changing her position; the danger being that the diver may be brought in contact with some submarine obstruction and that his air hose or life line may become badly fouled. Should either one happen to get a turn around some object or other and the diving vessel be moving, his only chance would be to sever the fouled line with his knife and signal to be hauled up with the other.

In case an emergency signal to haul a diver up is received at the surface, preparations should at once be made to replace a damaged hose and to send the diver down again to be properly decompressed. The relief diver should get ready and stand by for a call.

211. Considering that the reducing valves on low pressure air lines are usually set for 100 pounds per square inch, diving should not be attempted in a depth greater than that equivalent to 75 pounds pressure per square inch, or 168 feet of sea water, without first altering the setting of the reducing valve accordingly.

212. A Jacob's ladder, as shown in the drawing, inclosure (Z–2), provides a most convenient means of rest for a diver during the various stages of decompression.

213. With a proper air supply no difference could be detected by the divers in diving in shallow or deep water as regards their physical well being and powers of doing work, etc. The only difference in sensations was that of the change in the voice under high pressure. The diver's safety and amount of work he can perform depends very greatly upon expert attendance.

214. For the proper action of a diving apparatus under water a weighted belt of about 50 pounds is sufficient when the effects of tide and currents are not considered. To offset effect of tide on the diver, additional weight should be carried; the amount depending upon the diver's strength and the velocity of the current. If too much weight is added it will be found that the breast plate will rest heavily upon the diver's shoulders and that he may not be able to climb up the diving ladder.

215. A test of the Siebe, Gorman & Co.'s submarine escape apparatus is yet to be conducted. The delay in carrying out this test is due to the late delivery of the apparatus. When completed it will be made the subject of an additional and special report. (See Appendix 1 for report.)

216. Two special apparatus, Siebe, Gorman & Co.'s salvator apparatus and an ammonia helmet were submitted for test. These, however, had no connection with diving operations, and as proper facilities for testing them were not available but little was accomplished.

217. The salvator apparatus was tried under normal atmospheric conditions and is a practical device for administering oxygen in respirable and certain irrespirable atmospheres at normal pressures. No protection is provided for the parts of the body ordinarily exposed, excepting the mouth and nose. While it meets the claims of the manufacturer it is not recommended for naval use excepting, possibly, in hospital and ambulance work.

218. The ammonia helmet, previously referred to, depends for its proper action, upon the functioning of an oxygen generator which generates oxygen from a compound called oxylithe. A supply of oxylithe was not obtainable and, for which reason, the apparatus could not be tested. From an inspection of the ammonia helmet it is believed that work could be accomplished with it in irrespirable atmospheres for short periods, but that it would be very uncomfortable to the wearer. It is not believed that it would compare favorably with the most approved forms of mine-rescue apparatus designed for a similar purpose.

219. In concluding this report I desire to express my appreciation of the services rendered and the interest displayed in the deep-diving tests by Passed Asst. Surg. G. R. W. French, United States Navy. Whatever has been accomplished has been done with the aid of his scientific knowledge and advice.

220. It is further desired to invite attention to the excellent services rendered throughout these tests by Chief Gunner's Mates S. J. Drellishak, F. W. Crilley, and F. C. Nielson, United States Navy. These three men have been repeatedly and continuously exposed to severe hardships and the most strenuous duty imaginable. They have consistently displayed such resourcefullness, aptitude, and courage as to merit any reward that might be bestowed for the exhibition of similar qualities and attention to duty.

Gunner G. D. Stillson.

December 10, 1914.

[Inclosures.]

(A) Blue print of experimental diving tank.
(C) to (H) Records of tests of "Morse" and "Schrader" diving pumps.
(I) Blue print and description of air control valve.
(J) Blue print and description of improved regulating valve.
(K) Diagram of improved telephone apparatus.
(L) Sketch of telephone cable, connections, etc.
(M) Record of test of diver's self-contained diving lamp.
(N) Sketch of improved diving gloves and diver's underjacket.
(O) Blue print of proposed standard diving air-hose couplings.
(P) Sketch of improved diving belt.
(Q) Photographs of "Draeger" submarine escape apparatus.
(R) Record of important experimental dives.
(S) Sketch of test tank for use in testing diving pumps.
(T) Drawing of improved diving ladder.

(U) Sketch of arrangement of air flasks and connections for supplying air to divers from small boats.

(V) Tool for assembling pistons of diving pumps.

(W) Navy Diving Manual, 1905.

(X) Blue print of diving manifold.

(Y) Copies of correspondence from officers relating to diving.

(Z) Blue print of improved diving helmet with description.

(Z–1) Sketch of arrangements for diver's air supply on board U. S. S. *Walke*.

(Z–2) Sketch of arrangements of diving ladder, Jacob's ladder, etc., in a Navy sailing launch.

(Z–3) Blue print of recompression chamber.

[Inclosure (A).]

EXPERIMENTAL DIVING TANK.

[For description and method of operation see paragraphs 4, 5, and 6.]

INDEX TO NUMBERS.

1. Angle valve controlling pressure from compressor tank.
2. Gauge indicating diving tank pressure.
3. Brass stuffing box.
4. Pressure pipe on inside of tank.
5. Angle valve for diver's control of tank pressure.
6. Gauge indicating outside or pressure tanks.
7. Connections for air hose.
8. Blow-off valve for diving tank pressure.
9. Globe valve to cut out blow-off valve..
10. Branch to blow-off or exhaust line.
11. ½ inch by-pass to exhaust line for slow reduction of pressure.
12. Gauge indicating diver tank pressure.
13. Globe valve for control of exhaust in 1½-inch exhaust line.
14. Globe valve for control of exhaust in ½-inch exhaust line.
15. Free exhaust terminating in stock room.
16. Drain line for emptying tank to sewer.
17. House water supply.
18. Branch water supply to diver's tank.
19. ½ inch globe valve controlling water supply to filter.
20. Tee for ½ and 1½ inch branch for tank supply.
21. Globe valve for control of city water supply to tank.
22. 1½ inch city water supply to tank.
23. Filter for filtering city water for ½-inch supply to tank.
24. Delivery from filter to tank.
25. Connections for air hose from pumps.
26. Electric cable.

[Inclosure C.]

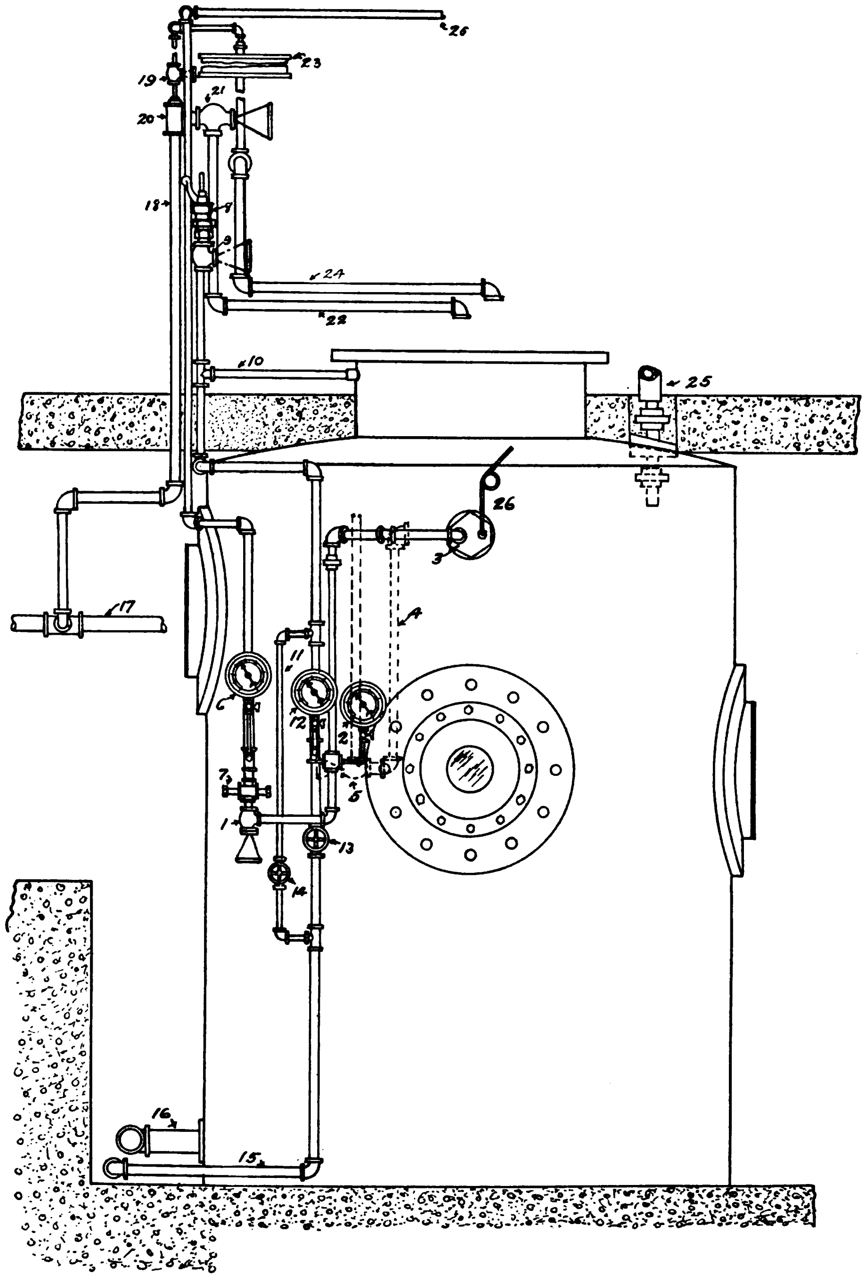
RECORD OF TESTS.

Schrader diving pump No. 65.

NOTE.—At the beginning of tests pump No. 65 was new; drawn from store shortly after delivery by manufacturer. Manufacturer was not aware of the fact that this pump was to be tested.

Date.	Total revolutions to date, run against 100 pounds pressure.	Loss in efficiency.	
		Test at beginning of run.	Test at end of run.
1914.		*Per cent.*	*Per cent.*
Feb. 19	93		12
27	221		14
Mar. 9	3,022		26
20	6,107		45

Schrader's men, who witnessed test, examined pump and found gaskets under cylinders defective.



DIVING TANK

RECORD OF TESTS—Continued.

Schrader diving pump No. 65—Continued.

Date.	Total revolutions to date, run against 100 pounds pressure.	Loss in efficiency.	
		Test at beginning of run.	Test at end of run.
1914.		*Per cent.*	*Per cent.*
Apr. 15	Started power test. Pump run at 36 revolutions per minute against 100 pounds pressure at intervals as indicated.		
15	7,575		21
16	26,795	21	37
16	Connecting rod bearings ran hot; transfer valve, upper inlet valves, and valve rod stuffing boxes leaking; repaired same.		
17	35,739		51
17	Set up on stuffing boxes and pipe connections.		
18	35,878		41
20	Test of left cylinder		27
	Test of right cylinder		63
	Test of both cylinders working together		50
20	Total revolutions to date, 36,702.		

NOTE.—It will be noted that the efficiency of the pump rapidly decreased toward latter part of test. In the last test, Apr. 20, there were no visible exterior leaks and the loss in efficiency is attributed to piston leakages, principally in the right cylinder. It would appear from the single cylinder tests that the average loss would be 45 per cent. The actual results obtained was slightly in excess of that amount, as indicated. An examination of the pump confirms the opinion that the pump frame and bedplate are not of sufficiently rigid construction; that pistons are not correctly designed, and that cooling system is inadequate. The fact that the pump was run at a speed of 36 revolutions per minute was in its favor for the reason that at a slower speed it would have been less efficient.

[Inclosure D.]

RECORD OF TESTS.

Schrader diving pump No. ——.

NOTE.—Schrader diving pump No. —— was drawn from store at beginning of tests. Had formerly seen much service, but had only recently been overhauled and repaired by A. J. Morse & Son, Boston, Mass.

Date.	Total revolutions to date, run against 100 pounds pressure.	Loss in efficiency.	
		Test at beginning of run.	Test at end of run.
1914.		*Per cent.*	*Per cent.*
Mar. 10	114		29
	Turned over to Schrader's for overhauling. New pistons (Schrader type) made and fitted.		
Mar. 20	2,551	15	16
23	4,450	16	18
Apr. 8	4,549		18
22	Started power test.		
22	9,875	18	21
23	18,900	17	42
	Pump doing badly and stopped for overhauling.		
24	21,238	29	40
25	23,740		44
28	31,762	40	59
29	Tested left cylinder.		40
	Tested right cylinder.		63
	Tested both cylinders.		56

NOTE.—Same conditions as mentioned in inclosure C. It may be noted that tests with pump cold show an improvement over tests at end of a run. This may be accounted for by a different rate of expansion between the cylinders and pistons. "Schrader" pistons are not fitted with spring rings under the cup leathers.

[Inclosure (E).]

Record of Tests.

Schrader diving pump No. ——.

[Same remarks as in Inclosure (D).]

Date.	Total revolutions to date, run against 100 pounds pressure per square inch.	Loss in efficiency.	
		Test at beginning of run.	Test at end of run.
1914.		*Per cent.*	*Per cent.*
Feb. 19	102	....	21
20	Overhauled and set up on leaky joints.		
Mar. 23	753	17	18
25	2,525	17	18
Apr. 6	2,874	17	18
May 1	Overhauled pump and set up on piston and nuts. Started power tests.		
1	6,827	16	33
4	14,253	32	55
	Overhauled pump. Found upper left inlet valve stuck wide open. Inlet-valve spring deformed. Replaced same with new one.		
5	18,383	32	41
6	21,869	39	42

Note.—Old pistons in this pump had been remodeled by A. J. Morse & Son.

[Inclosure (F).]

Record of Tests.

Morse diving pump No. 1366.

Note.—Morse pumps 1365, 1366, and 1367 were carefully tested in factory and results reported to the Bureau of Construction and Repair by the manufacturers. These particular pumps were drawn from store and tested as per the request of the makers.

Date.	Total revolutions to date, run against 100 pounds pressure per square inch.	Loss in efficiency.	
		Test at beginning of run.	Test at end of run.
1914.		*Per cent.*	*Per cent.*
Feb. 26	918	....	11
6	1,754	....	11
Mar. 10	3,585	....	11
May 9	Started power test.		
9	8,696	12	17
12	14,644	17	22
	Set up on transfer valve and gland nuts.		
13	15,832	12	17
	Set up on gland nuts.		
14	24,925	11	14
18	28,728	12	14
19	37,726	12	13
	Set up on gland nuts.		
20	42,785	11	12
21	50,618	12	15

Note.—This test is considered a creditable showing for the pump. Its efficiency is believed to be due to superior design and construction.

[Inclosure (G).]

RECORD OF TESTS.

Morse diving pump No. 1367.

NOTE.—Morse pumps Nos. 1365, 1366, and 1367 were carefully tested in factory and results reported to the Bureau of Construction and Repair by the manufacturers. These particular pumps were drawn from store and tested as per the request of the makers.

Date.	Total revolutions to date, run against 100 pounds pressure per sqaure inch.	Loss in efficiency.	
		Test at beginning of run.	Test at end of run.
1914.		*Per cent.*	*Per cent.*
Feb. 27	1,437		12
Mar. 3	4,664		14
4	5,771		14
6	7,990		14
9	8,090		14
Apr. 8	9,298		14
May 25	Started power tests.		
25	25,513	14	17
	Set up on cylinder-head bolts.		
26	28,891	14	16
27	31,186	14	16
28	34,662	14	16
29	Set up on gland nuts.		
29	39,054	12	18

NOTE.—Test considered satisfactory. Same remarks as in inclosure (F).

[Inclosure (H).]

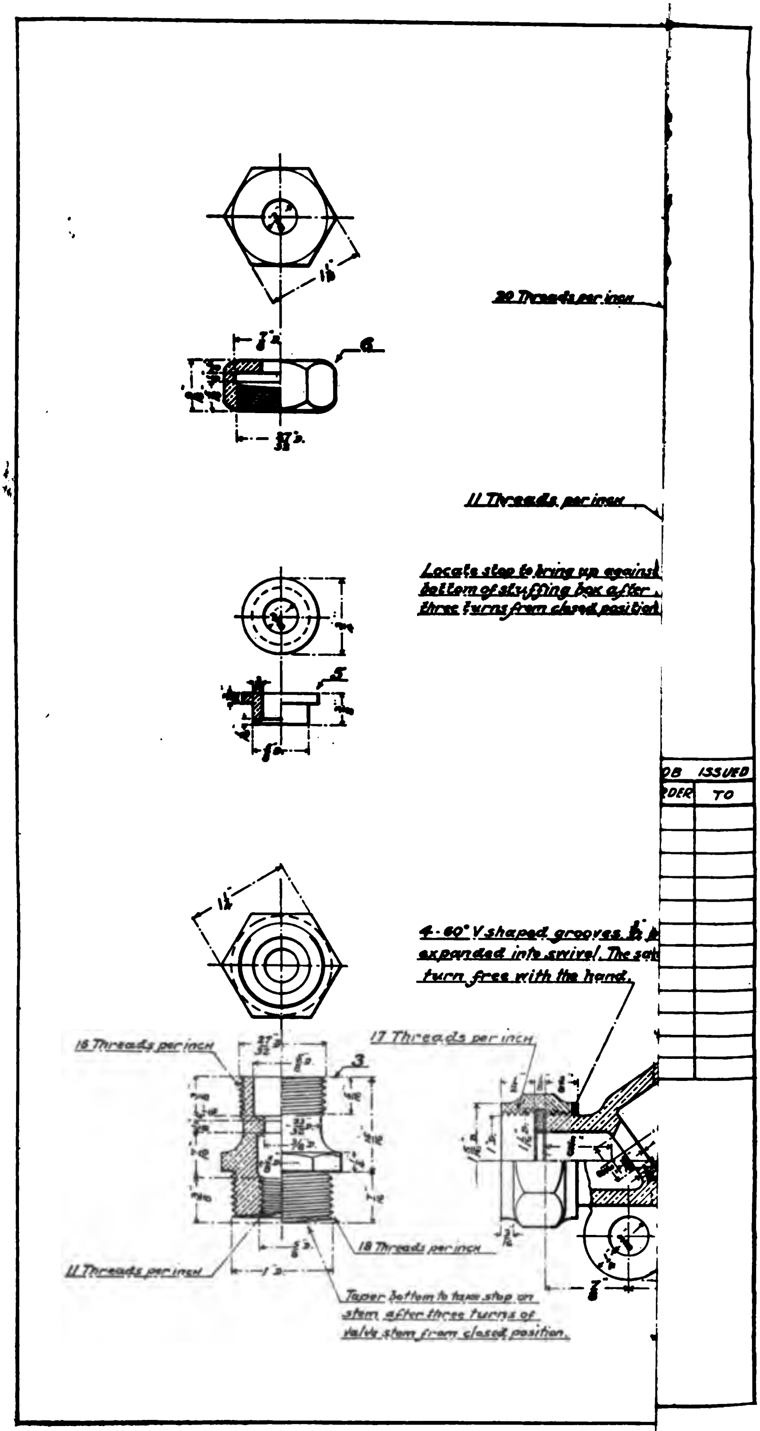
RECORD OF TESTS.

Morse diving pump No. 1365.

NOTE.—Morse pumps Nos. 1365, 1366, and 1367 were carefully tested in factory and results reported to the Bureau of Construction and Repair by the manufacturers. These particular pumps were drawn from store and tested as per the request of the makers.

Date.	Total revolutions to date, run against 100 pounds pressure per square inch.	Loss in efficiency.	
		Test at beginning of run.	Test at end of run.
1914.		*Per cent.*	*Per cent.*
Feb. 25	898		11
Mar. 3	3,561		13
Apr. 8	4,153		14
June 3	Started power test; overhauled pump.		
3	8,649	11	14
	Crank shaft ran warm; slacked back on brasses.		
4	11,887	14	20
	Set up on gland nuts.		
5	19,754	15	17
6	22,568	15	22
8	25,595	19	20
9	32,156	19	20
10	36,323	19	22
11	39,110	20	28

NOTE.—While this test is not as satisfactory as in the cases of pumps 1366 and 1367 the loss is not considered excessive. Upon examination, found one leather valve face considerably worn.


20 Threads per inch
11 Threads per inch
Locate stop to bring up against
bottom of stuffing box after
three turns from closed position
6
5
3
1½"
1⅛"
⅞"
27/32"
⅝"
JOB ISSUED
ORDER TO
4-60° V shaped grooves
expanded into swivel. The
turn free with the hand.
16 Threads per inch
17 Threads per inch
18 Threads per inch
11 Threads per inch
Taper bottom to take stop on
stem after three turns of
valve stem from closed position.

86353—15. (To face page 97.) No. 1.

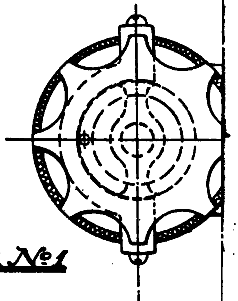


Fig. № 1

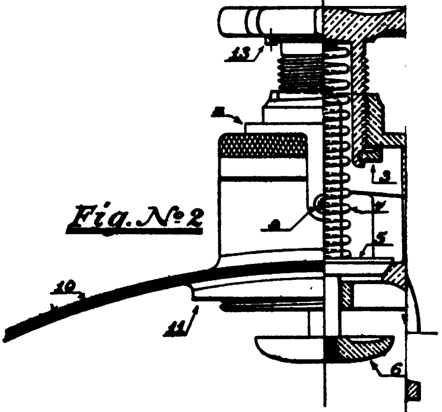


Fig. № 2

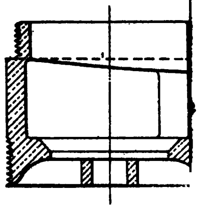


Fig. № 3

Valve

Section at B·B

86353—15. (To face page 97.) No. 2.

[Inclosure (I).]

DIVER'S AIR CONTROL VALVE.

[Patent applied for.]

1. The object of the device is to enable a diver to control the amount of air entering his dress. By its use air of varying pressures can be controlled; the dangers of overinflation are lessened; the rapidity of descent can be checked, and the diver is rendered independent of air control at the surface.

2. The valve is attached to the breastplate by means of a link which fits over a stud on the left front quadrant. A 3-foot length of diving hose is coupled between the control valve and the nonreturn valve on helmet, the diving hose being coupled to the other end of control valve and lead through a fair leader on the helmet. The hose is also stopped to the fair leader so that an undue strain will not come on the control valve and shift its position. The curved section of the valve body gives the proper lead to the air hose and causes the control valve operating wheel to remain in a convenient position for the diver. The valve and connections are located out of the way and do not inconvenience the diver in his movements and at the same time are always accessible. It is worn on the left side so as to leave the right hand free for holding onto lines, etc., when ascending or descending. On account of its construction much, little, or no air can be admitted to the inside of the dress by a turn of the wheel. The valve can not jam in either the open or closed position. It is easy to learn to operate, and every diver that has tried it is in favor of its adoption.

3. A diver often requires a sudden increase of air, and with this valve and proper connections can get it instantly and without the usual delay previously necessary. If in danger of "blowing up," he has simply to close it for a few moments.

4. When the diver has his air supply correctly adjusted (which he can do quickly without having to resort to signals to the surface), the valve requires no further adjustment until he again changes his position under water.

[Inclosure (J).]

DIVER'S IMPROVED REGULATING ESCAPE VALVE.

[Patent applied for.]

1. The improvement consists in: The construction tends to minimize the noises occurring in the helmet due to the escape of air, thus rendering telephonic communication less difficult.
2. The valve can be located conveniently for the diver without interference to vision by escaping bubbles.
3. The valve can be closed and entirely prevent escape of air.
4. A greater range of adjustment to the inflation of a diving dress is provided.
5. The valve can not jam in either open or closed position.

[Inclosure (K).]

IMPROVED TELEPHONE APPARATUS.

[Patent to be applied for.]

The improved telephone arrangement, shown in the accompanying drawings and described in the following, represents the installation considered most efficient for use in connection with diving apparatus and submarine operations.

The main features of the invention consists in the fitting of receiving instruments to a supporting device in such a manner that a receiver is held comfortably in place and in close proximity to each ear of the operator; in inclosing the operator's ears by means of flexible rubber ear pieces attached to the receivers, thus preventing local noises from reaching the ear drums in the ordinary direction; in arranging the receiving and transmitting circuits so that the local noises are not transmitted to an operator by his own transmitting instrument; and in the novel manner in which these are accomplished.

Call bells, buzzers, electric lights, annunciator systems, etc., have been experimented with and made to function satisfactorily in connection and in combination with the telephone circuits shown in the wiring diagram. This has been accomplished without increasing the number of conductors (three) in the telephone cable. For the reasons following, all such additions have been eliminated.

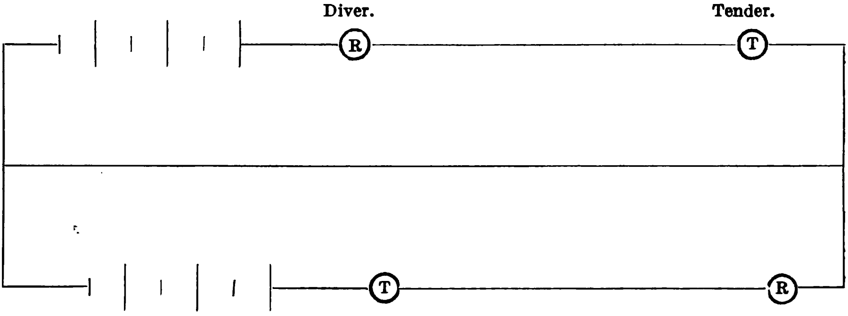
Efficiency of divers depends upon a rapid and reliable means of communication. Where dependence is placed upon call bells and the like for the diver to attract the attention of his attendant there is apt to be a considerable loss of time in getting or sending a message. If the diver happened to be in an emergency the slightest delay might easily end in disaster.

The diver needs no special call, as he can hear instantly anything said to him.

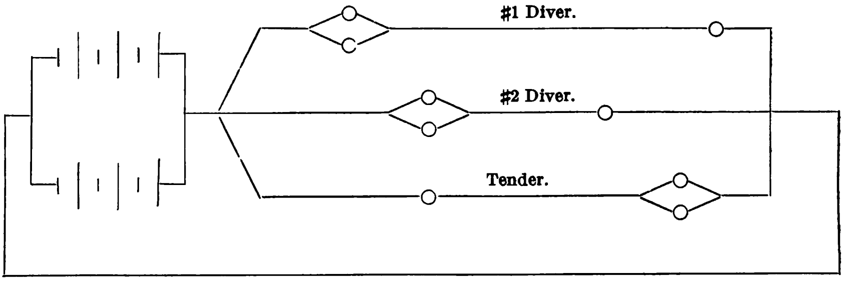
In deep water and when the diver is to attempt risky work it is desirable that communication with him should be instantaneous and continuous. In shallow water and when the work is not risky the ordinary methods of signaling proved an efficient means of attracting attention.

It is desirable that the construction of diving apparatus be as simple as the requirements of efficiency of service permit. Any addition or complication that does not add to efficiency is undesirable.

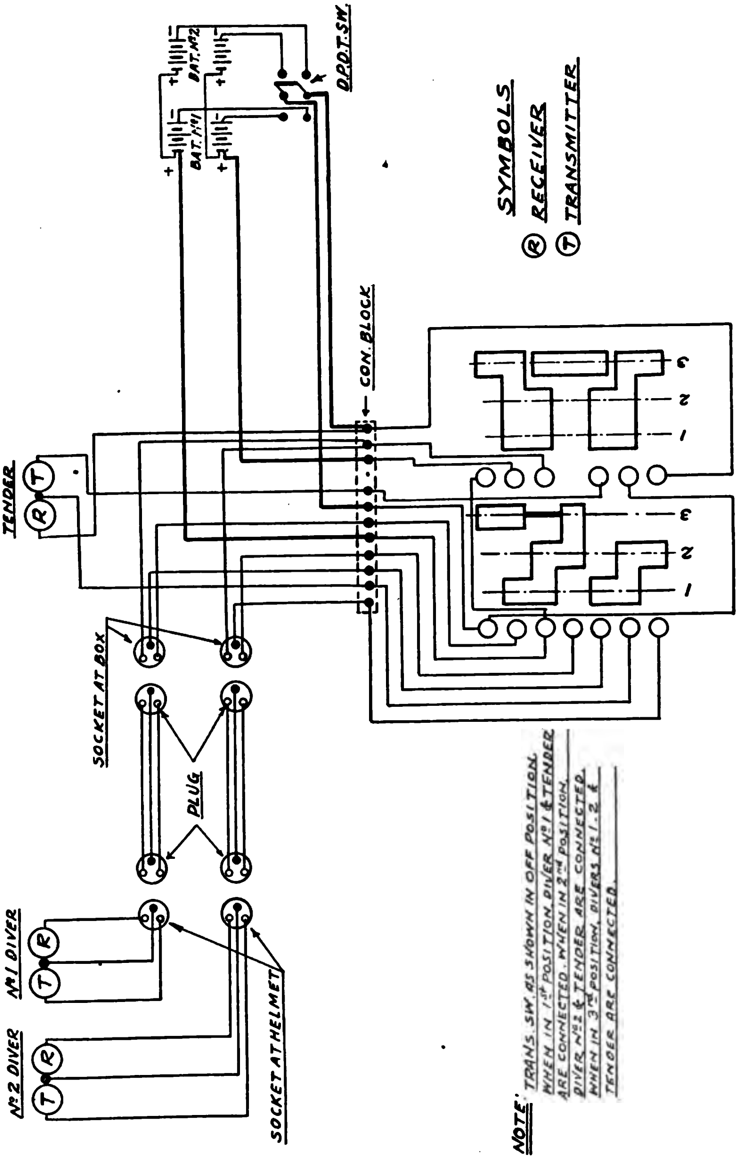
By referring to the wiring diagram it will be seen that on either of the first two positions of the transfer switch an extended diagram of the circuit is as follows:



On the third position of the transfer switch the result may be indicated by the following:



It will be noted that in this case a parallel system of wiring has been adopted. While a parallel connection is less efficient than the three-wire method it is more efficient than a series hook up. One of the two is necessary where a multiplicity of phones are in use and where the signal from any one transmitter must be reproduced in all receiving instruments.



NOTE: TRANS. SW. AS SHOWN IN OFF POSITION. WHEN IN 1st POSITION, DIVER № 1 & TENDER ARE CONNECTED. WHEN IN 2nd POSITION, DIVER № 2 & TENDER ARE CONNECTED. WHEN IN 3rd POSITION, DIVERS № 1. 2 & TENDER ARE CONNECTED.

DIAGRAM OF TELEPHONE CONNECTIONS FOR DIVING APPARATUS

When dressing the diver the headstall is put on before the helmet and the telephone receiver connection is made by an attendant reaching in through the faceplate opening; the wiring inside the helmet being installed with the convenience of this operation in view.

On account of the desirability of keeping in constant communication with the diver the ordinary combination hand instrument for tenders is unsuitable. It becomes tiresome to hold an instrument to the ear for long and, for which reason, a receiving instrument or a pair of receivers fitted to a light metal spring band passing over the attendant's head to hold them in place is recommended as the most convenient. The transmitter can be fitted on a flexible double conductor silk cord and designed to be habitually kept in a pocket of the tender's dress. When required for use it is quickly at hand.

Diver's head set.—Consists of the headstall, chin strap, telephone receivers, rubber earpieces, telephone cord, and connection piece.

Headstall.—For the purpose of holding the telephone receivers in the proper position over the diver's ears. Made of tanned cotton canvas duck. It is adjustable to any size or shape of head by means of lacings. It takes the place of the watch cap usually worn by divers. It is quite comfortable and can be worn for hours at a time without causing any inconvenience or discomfort.

Chin strap.—For the purpose of binding the telephone receivers firmly over the diver's ears and to prevent them from being rubbed or forced out of place from contact with the helmet. Made of soft grain leather and fitted with neat fitting buckle.

Telephone receivers.—Two (one for each ear) thin, watch-case size, waterproof, loud-talking telephone receivers, connected in parallel. The hard rubber cases are scored annularly to take the rubber earpieces. On the outer rim of each receiver is fitted two jack stays. The headstall is fastened to the upper ones. To the lower ones the chin strap is fastened.

Rubber earpieces.—For the purpose of properly locating the receivers and, also, of preventing the noises occurring in the helmet from interfering with telephonic communication. They are made flexible and in each one, in the location shown, is a small hole for the purpose of equalizing the air pressure on either side; necessary to the safety of the diver's ears.

Telephone cord.—In the helmet, as shown in the sketch, the transmitter is permanently secured by means of screws and clips and the telephone cord stopped to the wall of the helmet, a pair of leads being left loose near to and at one side of the front opening of the helmet.

The connection terminals.—For the receivers are made of hard rubber after the form of a pull socket. The spills being so arranged that the polarity of the instruments can not be reversed.

The diver's transmitter.—Is held by a clip and screws in a recessed box in a convenient location on the helmet. An ordinary, sensitive, loud-talking, watch-case size, waterproof transmitter is used and permanently connected to the circuit.

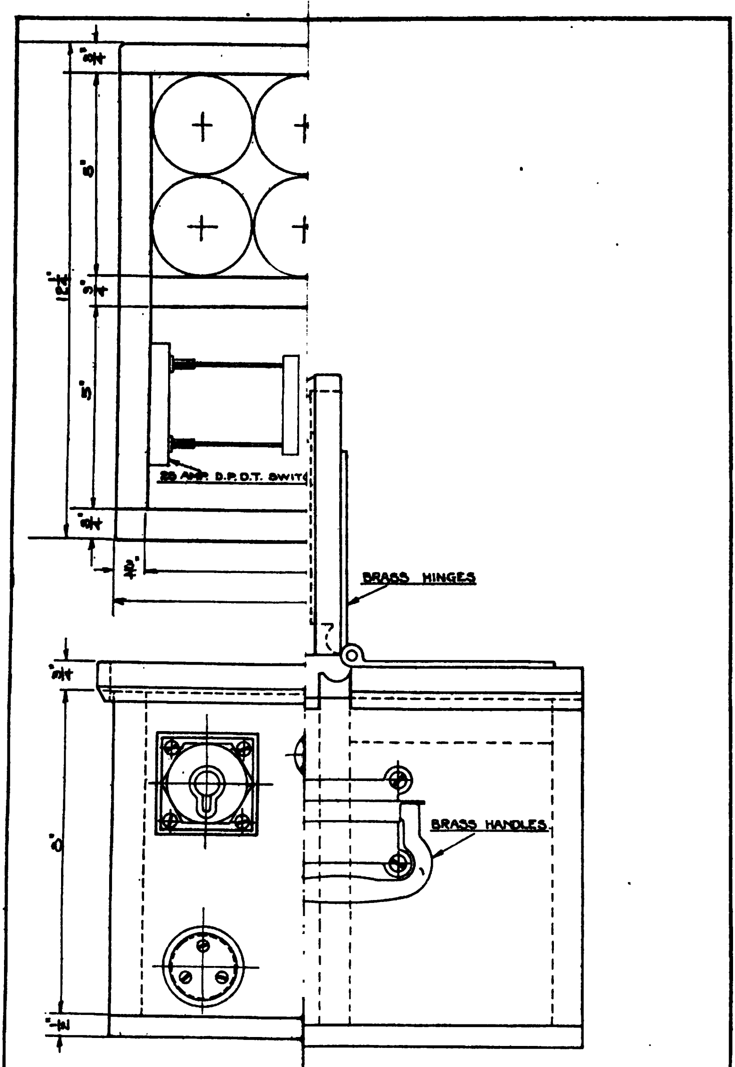
[Inclosure (L).]

DESCRIPTION OF TELEPHONIC CABLES, CONNECTIONS, ETC.

[Patent to be applied for.]

Telephone cable.—The life line and telephone cable are combined in one, as shown in the drawing. The braided line is made of oak bark tanned hemp rope. The combined cable is flexible and of a size to insure a safe grip and suitable strength. The couplings are as indicated. Rope of this description does not become slippery from use in salt or fresh water.

The battery box contains the dry battery (12 cells); the transfer switch; the connection board; a double pole, double throw, knife-blade switch; the wiring; cable terminal connections and a compartment for stowing the tender's instrument and two divers' head sets. The box is made of hardwood, finished and varnished. The batteries, are arranged and connected as shown in the wiring diagram, inclosure (K). The transfer switch is of the drum controller type and serves to close the circuits between the



NOTE. FITTINGS ON BOX TO
SIMILAR TO THOSE ON BOX A
NAVY YARD. N.Y.

APPROVED

33497 F

LT. C
ASST

BOX
FOR
DIVING TELEPHONE OUTFIT.

DRAWN BY H.C.F	
TRACED BY H.C.F	
CHECKED BY	DATE AUG. 27. 1914
CH. DRAFTSMAN	
MACH. DIV. U.S. NAVY YARD N.Y. 33497-F.	

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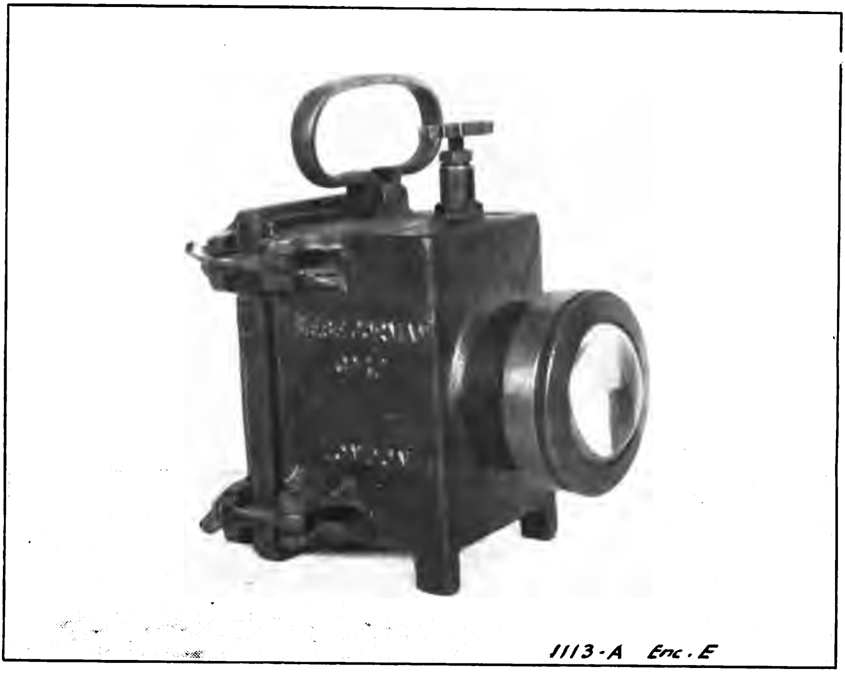

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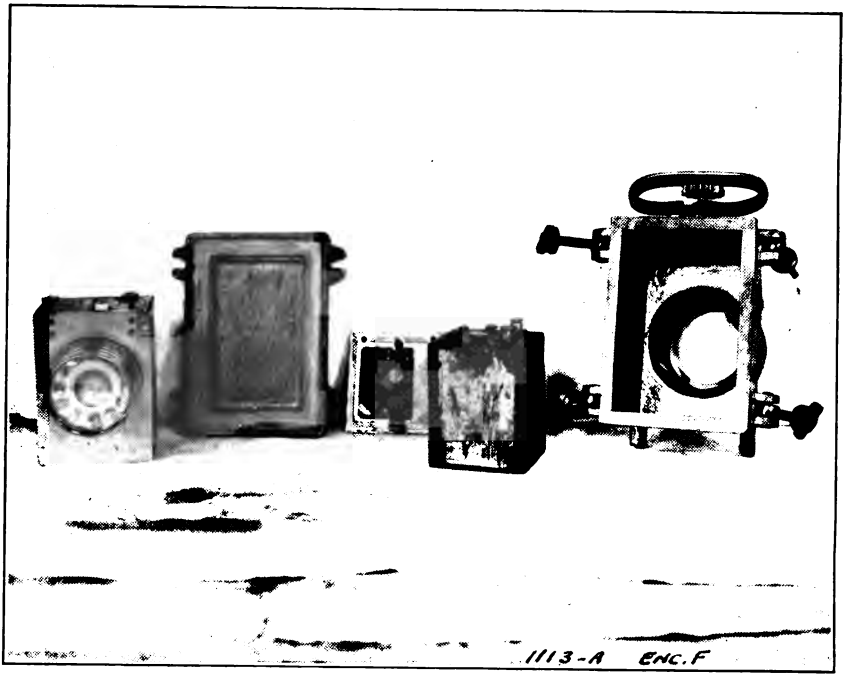
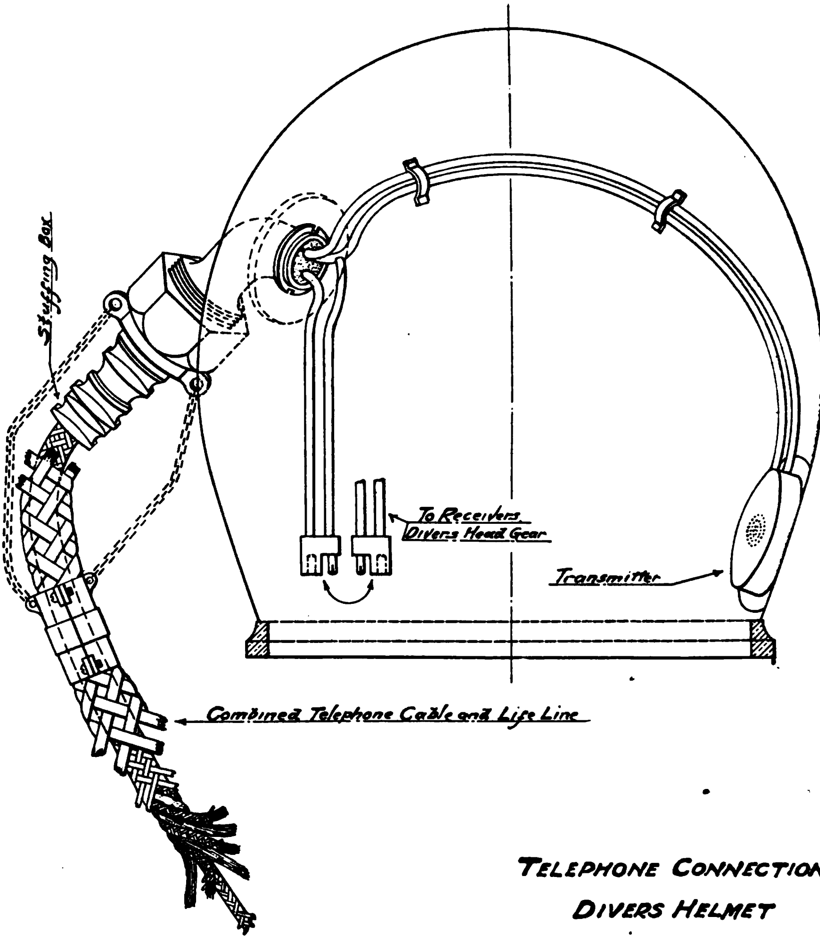


1113-A Enc. F

Diving Lantern submitted by U. S. Navy Experimental Diving Station.

proper spring fingers winding on the drum. From each finger a lead is taken to one of each of the twin binding posts on the connection board. All connections are marked, and a diagram of same is placed on the inside of the cover.



TELEPHONE CONNECTIONS
DIVERS HELMET

[Inclosure (M).]

NAVY YARD, NEW YORK,
Machinery Division.

SIR: The following shows the tests conducted on sample diving lantern recently submitted by you, the results obtained, and conclusions reached:

The lantern consists of a brass casing. In front of the casing is a bull's-eye lens. On top of this casing is a suitable handle and also a knob screw switch arrangement for opening and closing of the lamp circuit. The back of the casing consists of a detachable plate held to the casing by means of four screws. Inside of this casing is placed a metal box containing the two-cell lead storage battery. On front of this metal box is attached in a metal casing a small thin lens, a 1.8 candlepower frosted incandescent lamp and a holophane highly polished metal reflector. The cover of this box is also of metal and the electrical switch contacts for the lamp are attached on the inner side of the cover. This cover is clamped to the box by means of two screw nuts. A more detailed description can be obtained from photographs under inclosure attached. The overall dimensions of the lantern are 9¾ by 7¾ by 5⅞ inches and the weight is 16¾ pounds.

The following tests and inspection were conducted on this lantern:

(*a*) The lantern was turned upside down without any spilling or leakage of the electrolyte.

(*b*) The print under inclosure (*b*) shows the candlepower distribution of the lantern when the battery is in a fully charged condition.

(*c*) The battery on short circuit gives about 20-amperes current and after being short circuited for an interval of 10 seconds and the short circuit removed the voltage rose back to about normal voltage, showing the battery to have strong recuperative powers.

(*d*) The curve under inclosure (*c*) shows the candlepower variation with the time of burning of the lantern. The lantern shows a continuous burning on one charge for a period of 6 hours.

(*e*) The lamp consumes 1 ampere when the battery is fully charged.

(*f*) The battery when discharged at the rate of 1 ampere showed a capacity of 6-ampere hours.

Comparing this type of lantern with the one at present in use the following differences can be noted.

(*g*) The maximum candlepower of the lantern submitted is 21 candlepower, as against 100 candlepower obtained from the Navy standard lantern.

(*h*) The Navy standard type is heavier and larger than the sample submitted.

(*i*) The Navy standard type can be burned continuously with a very small depreciation in candlepower, as against a limited time of six hours burning and a rapid depreciation in candlepower obtained from the lantern submitted.

From the results of the tests made on the lantern submitted it is found that the capacity of the battery is small, the switch arrangement for turning on and off the lantern is defective, and the life of the lantern on one charge and illuminating intensity of the lantern are small.

The conclusions reached from the results obtained covers principally the question of adaptability. If a very great illumination is desired and air lines are run, the present standard diving lantern would be found the better, whereas if air line apparatus is not used and a portable lantern is desired, the sample submitted should be found satisfactory after some slight changes have been made.

Respectfully,

C. S. McDowell.

Mr. G. D. Stillson,
United States Navy Experimental Diving Station, Brooklyn, N. Y.

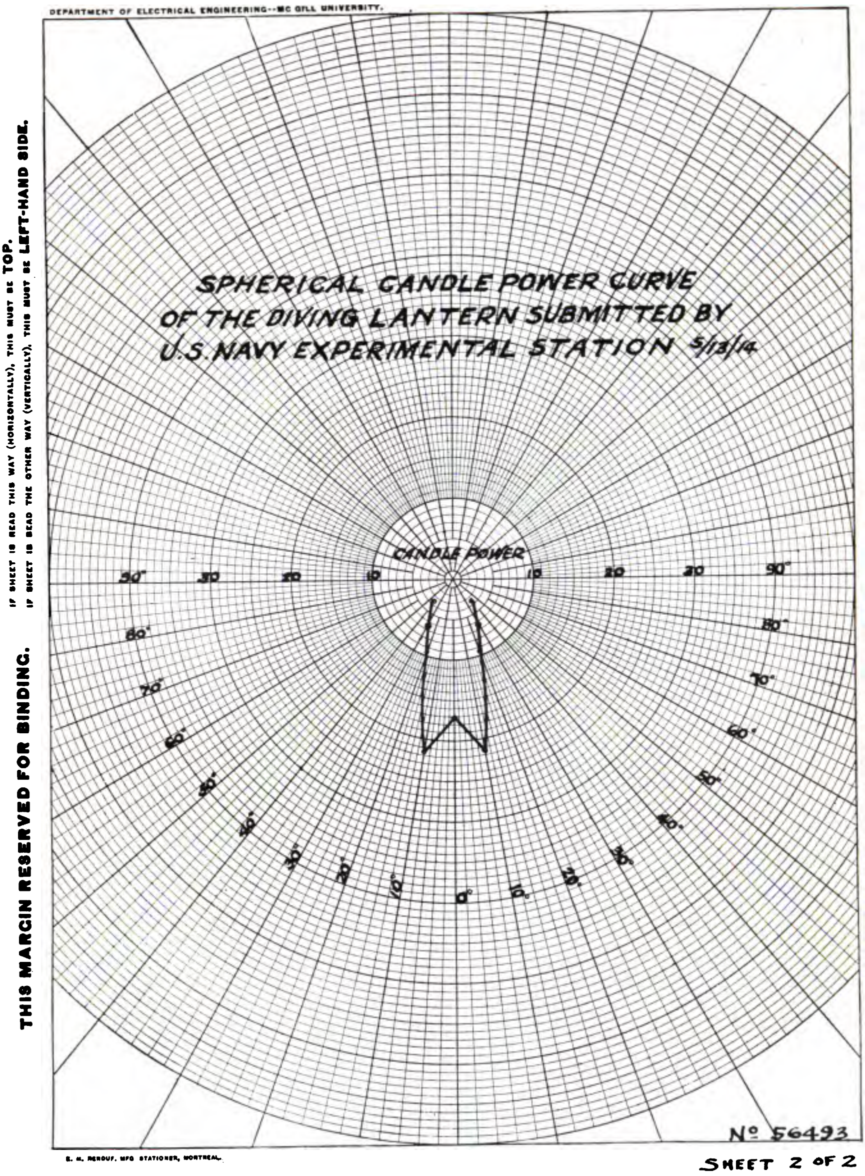
[Inclosure (N).]

Description of Improved Diving Gloves and Diver's Underjacket.

[Patent to be applied for.]

Improved diving gloves.—The general scheme and construction as shown in drawing. The gloves are made of good quality black rubber and strengthened where necessary. Long gauntlets; material tapering in thickness from wrist, and to fit over end of jacket sleeves. The outside surface of palm, thumb, and fingers to be covered with a suitable chafing material, cemented to rubber at the points most exposed to wear. Woolen gloves, conforming to the shape of the rubber gloves, to be provided, and worn when necessary in addition to the rubber gloves.

The improved diving gloves are worn under the cuff of the diving dress and attached to the end of sleeve on diver's underjacket by means of a leather or rawhide thong or lashing. Rawhide or leather strips for lashings are used to prevent injury to the



DEPARTMENT OF ELECTRICAL ENGINEERING--MC GILL UNIVERSITY.

SPHERICAL CANDLE POWER CURVE
OF THE DIVING LANTERN SUBMITTED BY
U.S. NAVY EXPERIMENTAL STATION 5/13/14

THIS MARGIN RESERVED FOR BINDING.

IF SHEET IS READ THIS WAY (HORIZONTALLY), THIS MUST BE TOP.
IF SHEET IS READ THE OTHER WAY (VERTICALLY), THIS MUST BE LEFT-HAND SIDE.

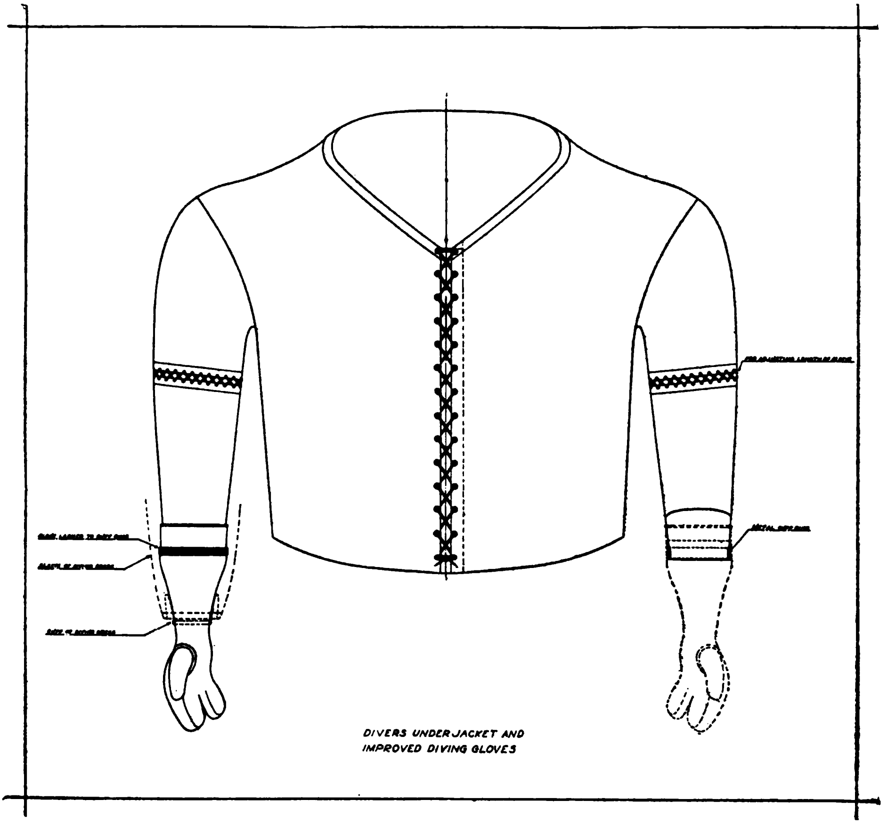
No 56493

E. M. RENOUF, MFG STATIONER, MONTREAL.

SHEET 2 OF 2

rubber gauntlet of the diving glove. When in use this type of glove eliminates the danger of a diving dress bursting when "blown up"; pressures within the diving dress can escape by way of the elastic cuff at end of sleeve of diving dress. Rubber wrist rings are unnecessary and these impediments to free circulation of blood to the hands can be dispensed with. Gloves can be made in different sizes and as they are flexible, neat fitting, etc., free use of the hands and fingers is possible in any temperature of water.

Diver's underjacket.—For the purpose of retaining diving gloves in position and to prevent cold air blowing through woolens. Worn under the diving dress and over diver's underwear. Made of soft, pliable, strong, and closely woven material. It adds much to a diver's comfort in cold water and as it is made close fitting tends to prevent air from inflating the diving gloves. Should it happen that the gloves do become inflated, the diver has simply to lower his hands in the water; the water pressure will force the air out again. In practice no difficulty has been experienced from this cause, as was the case with former types. At the sleeve ends of the jacket metal rings are turned in the material, as indicated. These are slightly concaved and into them the gauntlets of the diving gloves are securely fastened by lashings. This arrangement makes a neat and comfortable joint. The ring is slightly larger than a man's arm and its location is adjusted so that when worn it remains around the forearm and below the elbow.



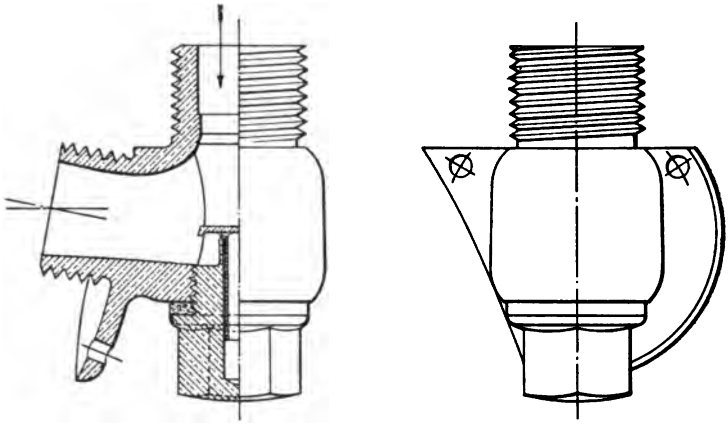
DIVERS UNDERJACKET AND IMPROVED DIVING GLOVES

When dressing the diver puts on underwear, diving jacket, diving gloves, diving dress, etc., in order named.

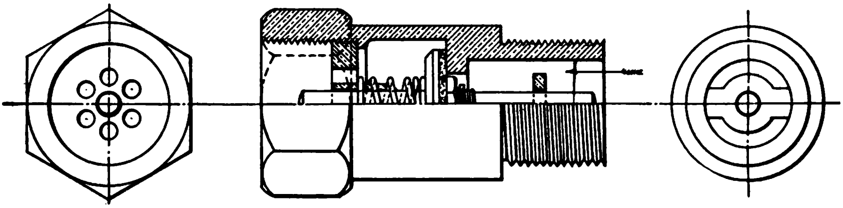
[Inclosure (O).]

Description of Improved Air Hose Couplings.

The design is a combination of Morse and Schrader couplings with improvements found desirable.



HEINKE VALVE



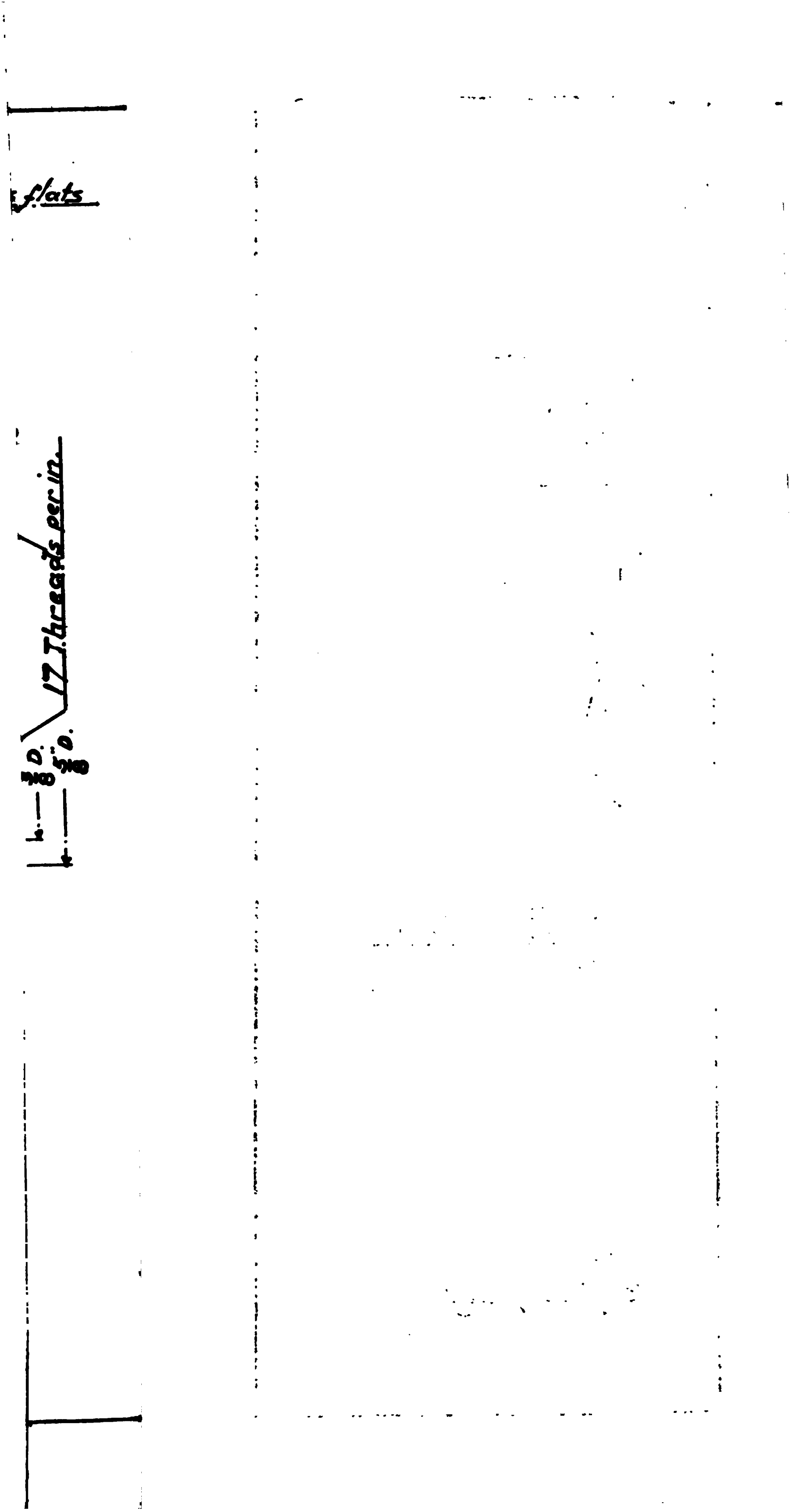
MORSE VALVE

INLET SAFETY VALVES
FOR DIVING APPARATUS

It will be noted that it is proposed to use metal hose clamps in place of wire seizings for attaching diving hose to shanks of couplings. This is a matter that it is expected will not be agreeable to certain manufacturers.

The reason for recommending the adoption of metal clamps in place of wire seizings is as follows:

The metal clamps when secured in place make a smooth, strong, tight joint. They can be fitted in place by any mechanic, and the only tools that need be used in the operation are a vise and a screw driver.


flats
17 Threads per in.
$\frac{3}{8}$ D.
$\frac{5}{8}$" D.

The wire seizings are usually put on by hand and the operation requires skill. The ends of the wire and its several turns must be soldered. Handwork can not be accomplished in as uniform a manner as mechanical work and is not as safe.

Repair work is difficult on board ship, and a fatal accident is known to have occurred due to a section of air hose, that had been wired on, pulling off the coupling while a diver was under water and stuck in a muddy bottom.

[Inclosure (P).]

DESCRIPTION OF IMPROVED DIVING BELT.

[Patent to be applied for.]

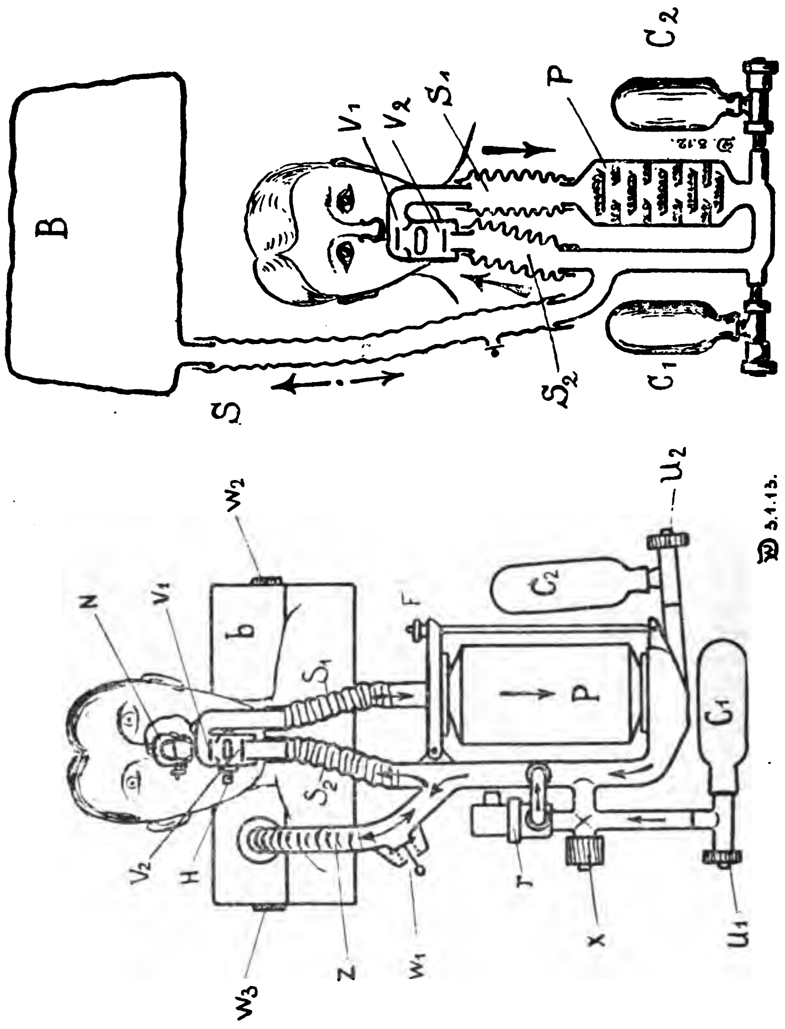
The general construction is shown in the drawing. Attention is particularly invited to the manner of attaching the brass links to which the straps are fastened. These are formed of ¼-inch round brass stock and set in the mound and cast in the upper center of the lead weights, thus providing an even balance and hang to the belt. In the lower figure is shown the curved buckles; this shape is necessary to permit passing of ends of straps when weight of belt is held by straps.

After a careful investigation it is found that a belt is superior to any other form of weight for divers. The principal objections to the belt weight has been hitherto the difficulty experienced in keeping it in position. To offset this a jock strap is provided, in addition to the shoulder straps, by means of which the belt is so adjusted that it will remain in any desired position. The jock strap also provides a suitable means for regulating the distance between corselet and crotch of diving dress. It may be worn or not as desired.

It will also be noted that the lead weights are readily detachable without injury to the belt; thus the belt is an adjustable one in all its features.

[Inclosure (Q).]

PHOTOGRAPHS OF DRAEGER SUBMARINE ESCAPE APPARATUS.



[Inclosure (R).]

RECORD OF IMPORTANT EXPERIMENTAL DIVES.

Experimental dive No. 1, February 24, 1914.

[Diver NIELSON.—To try communication.]

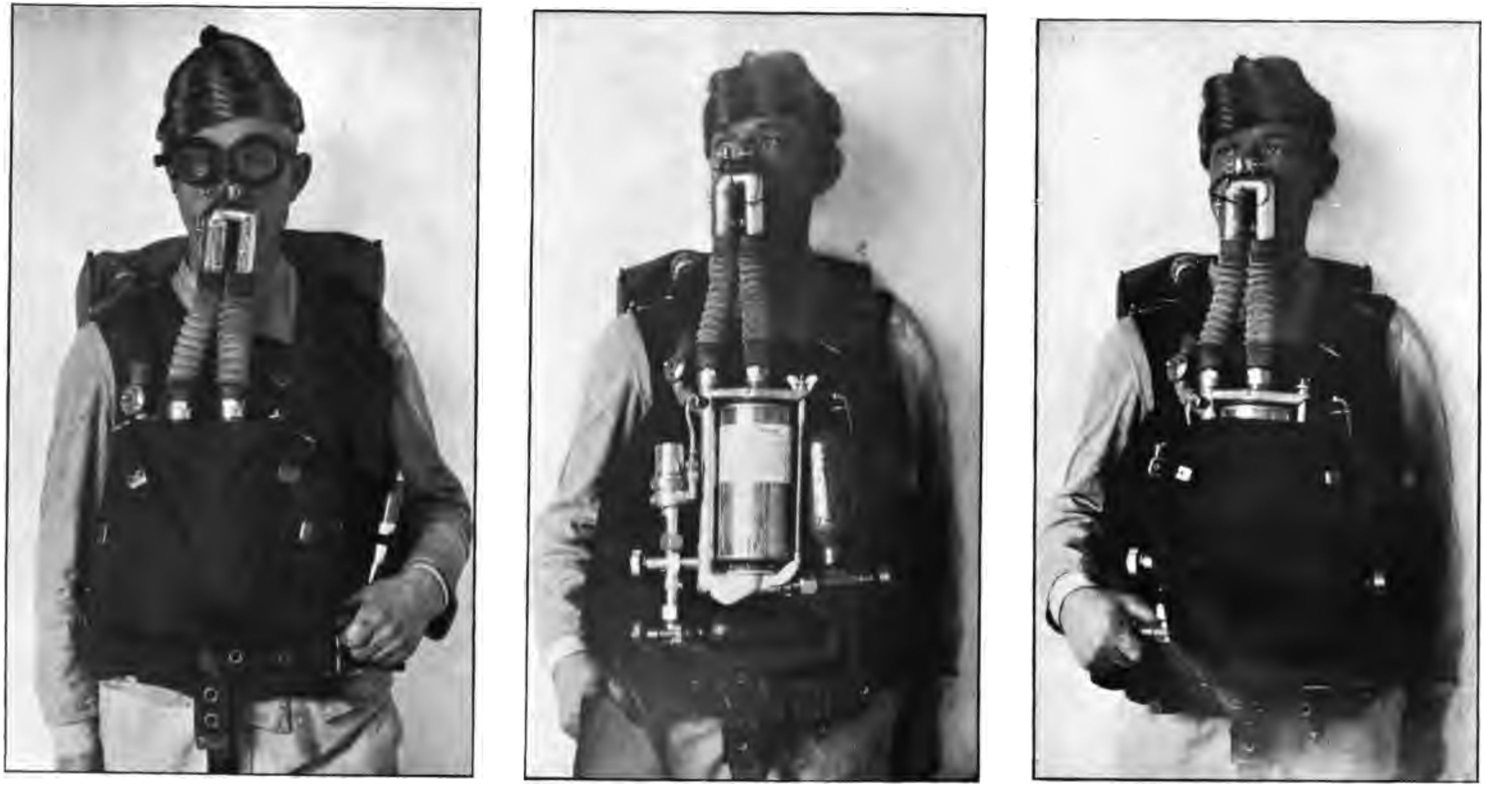
Diver dressed in Morse regulation outfit; pump No. 1366; legs of dress laced; helmet, Morse special.

Diver entered tank. Tested signals; results unsatisfactory. Diver called up to see if he understood prearranged signals—he had taken precaution to write them in pencil inside tank; reported temperature of water too warm; was perspiring considerably.

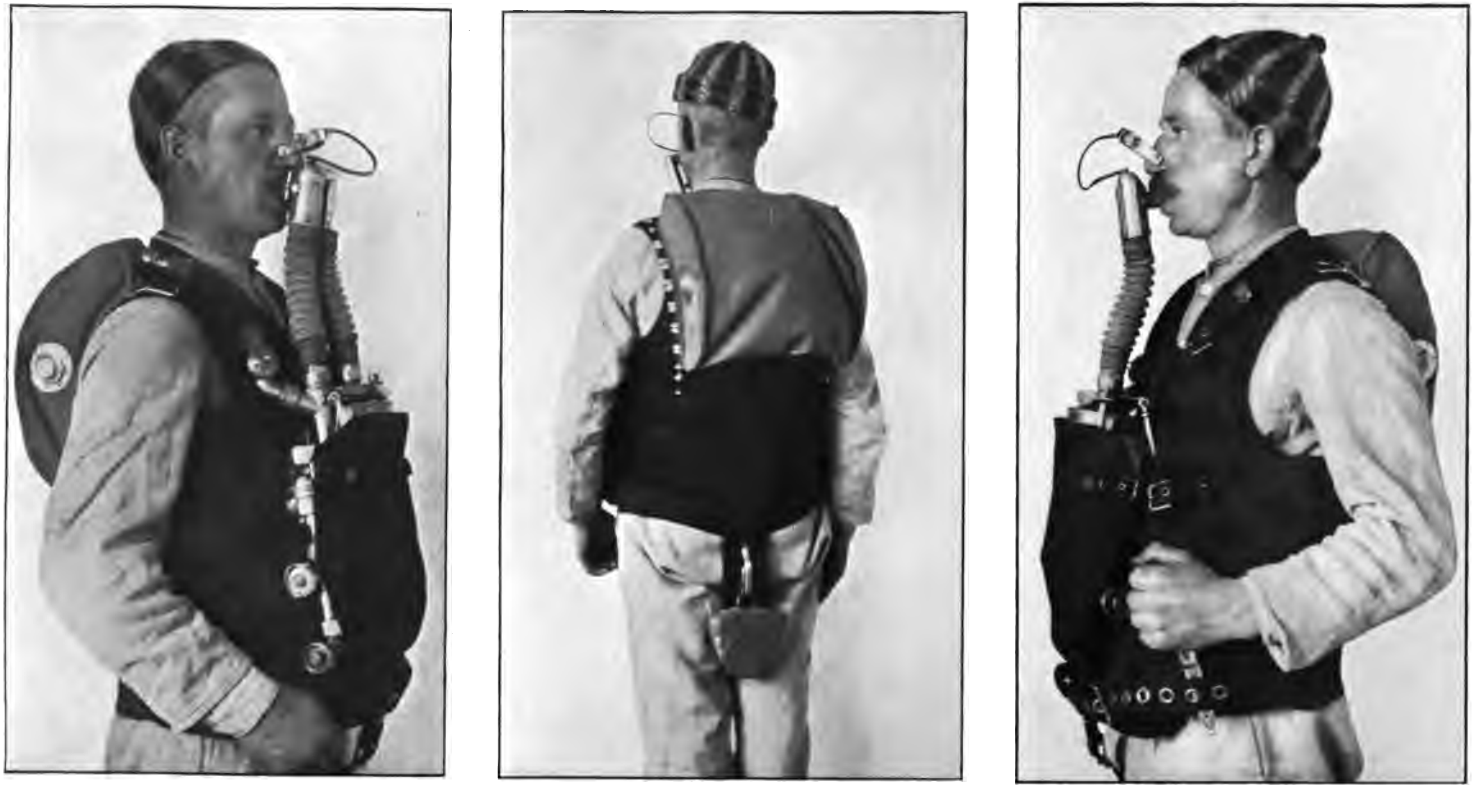
Diver sent down after temperature of water had been reduced from 72° to 65° F.

Compressed to 27 pounds (60 feet of sea water).

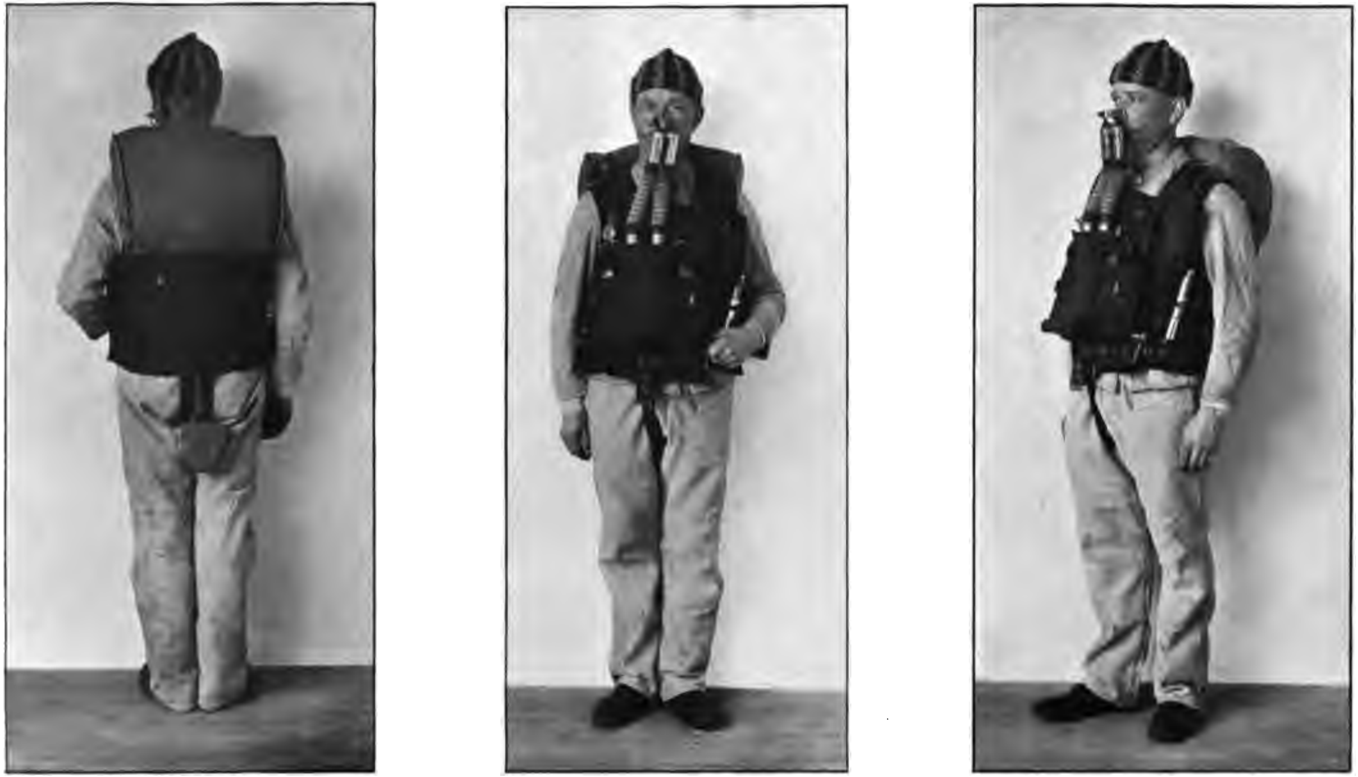
Telephone communication not established. No attempt made to use bell signals. Communication to and from diver by tapping on side of tank. Diver called up and reported temperature of water quite comfortable. Upon examination being made, found telephone connection broken. Tested out bell signals and found O. K.



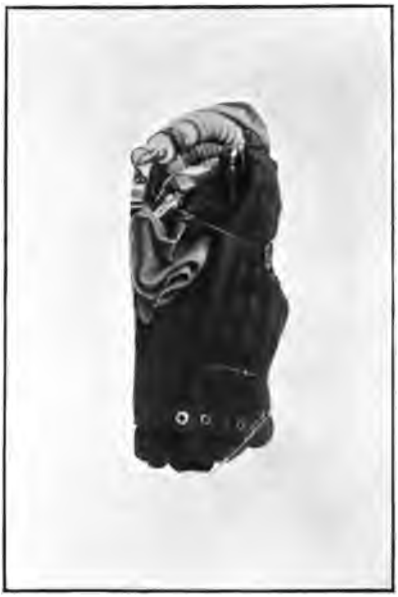
Draeger Submarine Escape Apparatus.



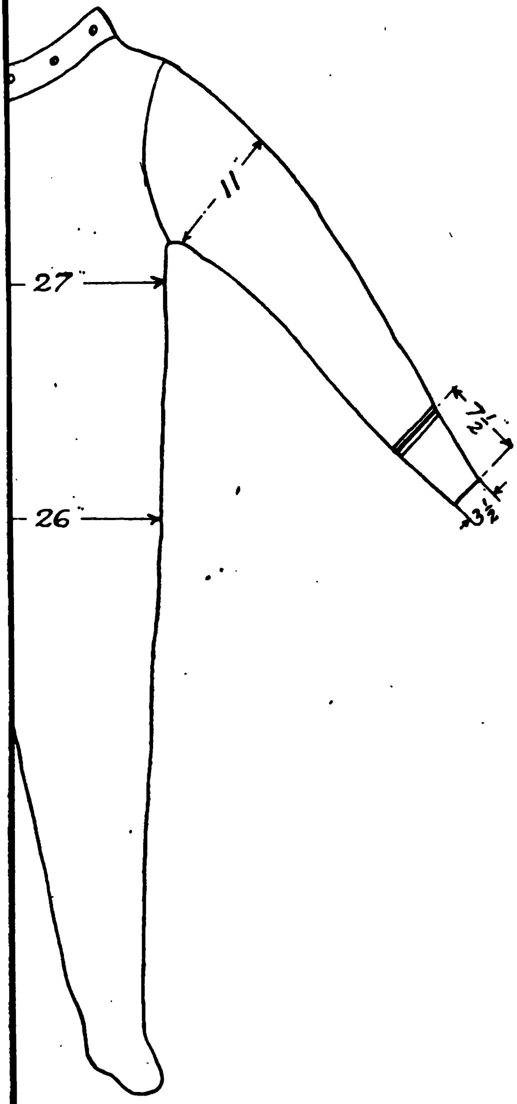
Draeger Submarine Escape Apparatus.



Drager Submarine Escape Apparatus.



Draeger Submarine Escape Apparatus.



PROPOSED CHANGES
IN
NAVY STANDARD DIVING DRESS

ESS
NG PATCHES)
)

Nº 56491

Experimental dive No. 2, February 25, 1914.

[Diver LOUGHMAN.—To try communication; no time taken.]

Diver entered tank dressed in Morse No. 3 dress with laced leggins over dress; same helmet and other equipment as in test No. 1.

Pressure raised to 10 pounds (22 feet of sea water). After about three minutes diver signaled for more air by tapping on side of tank, and repeated order through telephone. Speed of pump increased. At end of five minutes diver sounded emergency signal for immediate release. Opened exhaust valve and water drain valve. Started an additional cylinder. Diver blown to surface of water, then immediately fell to bottom of tank, landing on his feet. Removed manhole cover and it was seen that the air was exhausting freely from helmet and diver in no danger. Lowered ladder and diver climbed out of tank unassisted. Upon making an examination to ascertain cause of trouble found left sleeve of dress badly torn. Accident could not be accounted for by observers or diver.

The conclusions reached were that the rubber of the cuff was either torn by rubbing his wrist against the iron ladder or against the side of the tank. He was observed to enter tank without getting caught on anything. The cause of the variation in the inflation of the diver's dress was due to the varying degrees of elevation of the injured part. For instance: When he raised his arm to regulate his valves all the air within the dress was immediately exhausted and diver was subjected to a rather severe "squeeze" due to the pressure. When he lowered his arm the upper portion of the dress was distended with air and caused him to float quickly to the surface. The diver lost his head and, consequently, his control of self and apparatus. Such a circumstance in deep water would have proved disastrous. Had this diver been skillful he would have maintained his control by keeping himself in an erect position and the injured cuff at the proper elevation. By varying the height of the latter as necessary he could have controlled the inflation of his dress.

By chemical analysis it was proved that the injury was a mechanical one.

Experimental diving No. 3, February 25, 1914.

[Diver STILLSON.—To try out signals and conditions in tank; no time taken.]

Used Morse dress with laced legs, other equipment same as in test No. 18, experiment No. 2. Tank filled with cold water (temperature 50° F.).

Diver entered tank, tried air supply, and signaled for ladder to be removed, and to secure manhole cover. Increased pressure gradually from 0 to 50 pounds in 15 minutes (112.5 feet sea water); could not hear bell inside tank, but tapping lightly could be heard both inside and outside tank plainly. Could not hear through telephone, but diver's voice through telephone could be heard plainly by three listeners outside of tank. Phone message by diver answered from outside by holding a piece of paper with message written in pencil outside of observation window. Remained under pressure 10 minutes. Decompressed in 12 minutes in two stages. Pump used, No. 1365.

Experimental dive No. 4, February 26, 1914.

[Diver CRILLEY.—To try Schrader telephone and using air from two pumps coupled together.]

	p. m.
Entered water	1.56
Manhole cover secured	2.02
Pressure:	
5 pounds	2.03
15 pounds	2.05
25 pounds	2.06

Pressure—Continued.	p. m.
55 pounds	2.08
57 pounds	2.09
75 pounds (201.9 feet)	2.10
90 pounds	2.11
Opened exhaust valve	2.13
Pressure:	
35 pounds	2.18
27 pounds	2.21
17 pounds	2.24
13 pounds	2.29
9 pounds	2.36
5 pounds	2.46
0 pounds	3.06

Total time of compression 15 minutes.

Total time of decompression 53 minutes.

Total time at 90 pounds pressure 2 minutes.

Total time in water 1 hour and 10 minutes.

$\frac{90}{14.7}\times 33=$ formula for calculating equivalent depth of sea water to 90 pounds pressure (33 feet=height of sea water barometer at atmospheric pressure).

Could hear diver plainly through phone at all times during test, but not vice versa. Air supply hardly sufficient. Diver at rest during compression. Mild exercise during decompression. Diver's condition at all times during and after test normal. This dive, relative to subjection to air pressure, believed to be an American record, and excelled only during British Admiralty diving tests by Gunner Catto and Lieut. Damant, both of His Majesty's Royal Navy.

Experimental dive No. 5, February 27, 1914.

[Diver NORLIN, chief gunner's mate, *North Dakota.*—To determine practicability of men with little experience attempting to dive in deep water.]

Schrader helmet and phone; Morse dress. Pumps Nos. 1367 and 1316.	p. m.
Diver entered tank, 1 pump, 1 cylinder	3.27
Cover secured	3.30
Pressure:	
12½ pounds	3.33
22½ pounds, 2 cylinders	3.36
27½ pounds	3.37
32½ pounds, 2 pumps, 3 cylinders	3.38
55 pounds, 4 cylinders	3.39
75 pounds	3.40
75 pounds (168 feet)	3.43
22½ pounds, 1 pump, 2 cylinders	3.46
15 pounds, 1 cylinder	3.49
9 pounds	3.54
4½ pounds	4.02
0 pounds	4.12
Diver called up, out of tank; face plate removed	4.16

Condition normal. Same difficulty with phone as in test No. 4.

Experimental dive No. 6, March 3, 1914.

[Diver Gerdts.—To test Morse telephone.]

Morse dress with laced legs; Morse helmet and phone; pumps No. 1367 and 1316.

	p. m.
Pressure:	
5 pounds, 1 pump, 1 cylinder	1.45
11 pounds	1.51
15 pounds, 2 cylinders	1.56
25 pounds	2.01
30 pounds (66 feet)	2.02
30 pounds, started to decompress	2.05
10 pounds, 1 cylinder	2.06
0 pounds	2.08
Diver called up	2.10

Total time in water 22 minutes.

Total time to come to surface from 66 feet 6 minutes.

Telephone operated from diver to attendant only.

Diver reported he knew phone was in working order, but could not understand what was being said to him on account of noise from pump and from bubbles escaping from regulator valve.

Experimental dive No. 7, March 3, 1914.

[Diver Gerdts.—To test Morse telephone with noise of pumps eliminated.]

Same dress and equipment as in Experiment No. 6.

	p. m.
Diver entered tank	2.20
Cover secured	2.22
Pressure:	
5 pounds, 1 pump, 1 cylinder	2.27
10 pounds	2.30
15 pounds, 2 cylinders	2.31
20 pounds	2.32
25 pounds, 2 pumps, 3 cylinders	2.33
35 pounds	2.34
40 pounds	2.37
45 pounds	2.37½
50 pounds	2.38
60 pounds (132 feet), 4 cylinders	2.39
60 pounds, commenced decompression	2.40
52½ pounds (115 feet), reduced from 132 feet on account of short air supply	2.41
52½ pounds	2.52
15 pounds, 1 cylinder	2.55
10 pounds	2.57
5 pounds	3.02
0 pounds	3.12
Diver called up condition normal	3.15

Noise from pumps was eliminated by pumping into a small tank and supplying air to the diver as from an accumulator. This arrangement, however, did not increase the efficiency of the telephone.

Experimental dive No. 8, March 4, 1914.

[Diver Drellishak.—To try out Morse commercial type telephone.]

Morse helmet, special shoes, weights, and dress used; pumps Nos. 1367 and 1316 used.

	p. m.
Diver entered tank	2.10
Cover secured	2.14
Pressure:	
15 pounds, 1 cylinder	2.16
30 pounds, 2 cylinders	2.17
40 pounds, 3 cylinders	2.18
60 pounds (132 feet), 4 cylinders	2.19

Diver signaled for more air, to give him which it was necessary to decompress.

Pressure:	
52½ pounds	2.20
45 pounds, 3 cylinders	2.21
15 pounds, 1 cylinder	2.23
10 pounds	2.26
5 pounds	2.31
0 pounds	2.36
Diver called up	2.39

Telephone functioned well until second pump was connected, when communication was kept up with difficulty. When second pump was stopped, telephone communication was excellent. This test was conducted with noise from pumps eliminated by the use of a tank in air line.

Experimental dive No. 9, March 4, 1914.

[Diver Drellishak.—To try Morse commercial type of telephone.]

Same equipment as in test No. 8, but with diver's supply hose connected direct to pumps.

	p. m.
Diver entered tank	2.48½
Cover secured	2.51
Pressure:	
15 pounds, 1 cylinder	2.53½
30 pounds, 2 cylinders	2.55
35 pounds (78 feet), 3 cylinders	2.55½
35 pounds, started to decompress	2.58
25 pounds	2.59
15 pounds	3.02
10 pounds	3.07
5 pounds	3.12
0 pounds	3.22
Diver called up	3.25

Same result with telephone as in test No. 8.

Experimental dive No. 10, March 5, 1914.

[Diver NIELSON.—To try out Morse commercial type of telephone.]

Same equipment as in tests Nos. 8 and 9, except in case of weights. In this test diver used Schrader belt weights.

	p. m.
Diver entered water	2. 12
Cover secured, 1 cylinder	2. 15
Pressure:	
10 pounds	2. 16
30 pounds, 2 cylinders	2. 17
40 pounds	2. 18
50 pounds, 3 cylinders	2. 19
75 pounds (168 feet), 4 cylinders	2. 21

Diver exercised himself by taking box 2 by 2 by 2 feet, filled with 80 pounds of pig lead, and carrying it around in tank for 5 minutes; air supply ample.

Pressure:	
75 pounds (started to decompress)	2. 25
22½ pounds	2. 28
17½ pounds, 2 cylinders	2. 30
15 pounds, 1 cylinder	2. 37
10 pounds	2. 45
5 pounds	2. 52
0 pounds	2. 55
Diver called up	2. 58

Telephone functioned perfectly.

Experimental dive No. 11, March 5, 1914.

[Diver Chief Gunner's Mate COFFEY, U. S. S. *North Dakota*.—To try out Morse type of telephone.]

Same equipment as in previous test.

	p. m.
Diver entered tank, 1 cylinder	3. 13
Cover secured	3. 17
Pressure:	
15 pounds, 2 cylinders	3. 18
30 pounds, 3 cylinders	3. 20
45 pounds, 4 cylinders	3. 21
60 pounds	3. 22
75 pounds (168 feet)	3. 23
75 pounds, started decompression	3. 25
17½ pounds	3. 30
15 pounds, 2 cylinders	3. 33
9 pounds, 1 cylinder	3. 35
5 pounds	3. 41
0 pounds	3. 48
Diver called up	3. 49

Telephone functioned perfectly.

Tests Nos. 30 and 31 (experiments Nos. 10 and 11) seem to indicate that telephone troubles during latter parts of tests Nos. 28 and 29 were on account of diver and not due to instrument.

Experienced diver in old method. Had never dived before to depth exceeding 90 feet.

Experimental dive No. 12, March 6, 1914.

[Diver LOUGHMAN.—To try out Draeger telephone.]

Morse helmet, dress, and weights. Pumps Nos. 1365–1366.

	p. m.
Diver entered water, 1 cylinder	2.10
Cover secured	2.20
Pressure:	
15 pounds, 2 cylinders	2.25
30 pounds	2.30
35 pounds, 3 cylinders	2.33
45 pounds	2.36
53 pounds, 4 cylinders	2.37
75 pounds (168 feet)	2.49
75 pounds, started decompression	2.49
22½ pounds	2.52
17½ pounds, 2 cylinders	2.55
10 pounds, 1 cylinder	2.58
5 pounds	3.05
0 pounds	3.15
Diver called up	3.22

Telephone communication maintained throughout the test but with difficulty. Diver stated that he could hear best at high pressures, but all the time attendant's voice sounded far away. Diver was suffering from a slight cold and as the pressure affected his ears the best results might not have been obtained. He also reported that in making an effort to keep his ear close to receiver he strained the cords in his neck and that he felt as if he had a stiff neck.

Loughman is a tall man, slender, and with a long neck. He can reach his ear to receiver where other men can not.

Experimental dive No. 13, March 9, 1914.

[Diver CRILLEY.—To try out Draeger telephone with new batteries (10) volts.]

Same apparatus as in previous test. Pumps Nos. 1316 and 1367.

	p. m.
Diver entered tank, 1 cylinder	1.58
Cover secured	2.01
Pressure:	
10 pounds	2.02
15 pounds, 2 cylinders	2.04
30 pounds, 3 cylinders	2.05
50 pounds (112.5 feet)	2.07
50 pounds, stopped both pumps, started to decompress	2.28
15 pounds, pumps stopped	2.31
15 pounds, started 1 pump, 1 cylinder, 28 revolutions	2.34
9 pounds, 25 revolutions	2.36
5 pounds	2.41
0 pounds	2.51
Cover removed	2.53
Diver called up	2.55

Test of phone considered satisfactory, though operation not as good as that of Morse commercial type with double receiver held close to diver's ears.

In this test the experiment was made of stopping the diver's air supply during decompression for six minutes, a longer time than consciousness could probably be maintained in a diving dress under ordinary conditions at one level and demonstrated a method of rescuing a diver in case of injury to his air supply. The test could easily have been prolonged in case of necessity.

It is proposed that in case of a badly fouled diver to send a relief diver down with a new line of hose for the fouled diver, cut him clear of all entanglements, pump his dress full of air, close his valves, disconnect his hose, couple on new line of hose, and then decompress him in the regular manner.

Experimental dive No. 14, March 10, 1914.

[Diver GERDTS.—To test Morse commercial type diver's telephone, with impedence coil and condenser (Draeger type) connected in circuit. Draeger hand phone used by attendant.]

Morse helmet, dress, and equipment.

	p. m.
Diver entered, 1 cylinder	1.57
Cover secured	2.00
Pressure:	
15 pounds, 2 cylinders	2.10
30 pounds, 3 cylinders	2.15
55 pounds, 4 cylinders	2.15½
60 pounds,	2.18
75 pounds (168 feet)	2.22
75 pounds, started decompression	2.22
22 pounds	2.26
22 pounds, started 1 pump, 1 cylinder	2.26½
17 pounds	2.28
9 pounds	2.36
5 pounds	2.43
0 pounds, pumps stopped at beginning of decompression for 4½ minutes	2.53
Removed cover	2.54
Diver called up	2.55

Diver's condition, normal. Telephone operated satisfactorily, though not as well as during tests 30 and 31, experiments Nos. 10 and 11. By placing his hand over the exhaust valve, diver muffled sound of bubbles somewhat. During first part of test diver troubled by pains in ears due to effects of slight cold, which probably accounts for difficulty he experienced in hearing messages from attendant. During latter part of test telephone seemed to work better.

Experimental dive No. 15, March 10, 1914.

[Diver DRELLISHAK.—To try effects of varying location of regulating valve.]

Schrader bolt type, Navy standard helmet, dress, and equipment. Pumps 1365 and 1367.

	p. m.
Entered tank, 1 cylinder	3.10
Cover secured	3.14
Pressure:	
30 pounds, 2 cylinders	3.15
50 pounds, 3 cylinders	3.15½
60 pounds, 4 cylinders	3.16
70 pounds, 5 cylinders	3.16½
75 pounds (168 feet)	3.17
75 pounds, started decompression, stopped all pumps	3.17½
17 pounds, started 1 pump, 1 cylinder	3.19
13 pounds	3.21

Pressure—Continued.	p. m.
9 pounds	3. 24
5 pounds	3. 29
0 pounds	3. 34
Cover removed	3. 35
Diver called up, condition normal	3. 36

Compression was at the rate of approximately 1 foot submergence per second. Regulation helmet was used so that diver could make comparison on next dive with valve in new location. No difficulty experienced.

Experimental dive No. 16, March 11, 1914.

[Diver DRELLISHAK.—To try out Schrader regulation bolt-type helmet and to ascertain proper location of regulating valve.]

Schrader equipment. No telephone. Pumps Nos. 1366 and 1367. Capacity of air space in helmet, above center of regulating valve, 470 cubic inches.

	p. m.
Entered tank, 1 cylinder	2. 45
Cover secured	2. 46
Pressure:	
0 pounds	2. 48
15 pounds, 2 cylinders	2. 49
50 pounds, 5 cylinders	2. 49½
50 pounds, stopped pumps (112.5)	2. 56
13 pounds	2. 59
13 pounds, started 1 pump, 1 cylinder	2. 59½
9 pounds	3. 01½
5 pounds	3. 04½
0 pounds	3. 11½
Cover removed	3. 13
Diver called up	3. 14

Diver could not notice any signs of CO_2; ventilation apparently good. From observation window the suit appeared too flat and diver too heavy. No telephone was used and communication by ordinary methods of signaling was very unsatisfactory. Value of a telephone clearly demonstrated, and it was decided to never dive again, unless necessary, without a telephone.

Experimental dive No. 17, March 11, 1914.

[Diver DRELLISHAK.—To test helmet, same kind as in above test (42) with regulating valve lowered to a position to give a volume of 500 cubic inches of air (atmospheric pressure) above center line of valve.]

Same equipment and pumps as in previous test. Schrader telephone.

	p. m.
Entered tank, 1 cylinder	3. 28
Cover secured	3. 29
Pressure:	
0 pounds	3. 31
50 pounds, 4 cylinders	3. 33
50 pounds (112.5 feet), stopped pumps	3. 40
13 pounds, started 1 pump, 1 cylinder	3. 43
9 pounds	3. 46
5 pounds	3. 53
0 pound	3. 59
Cover removed	4. 04
Diver called up	4. 05

Diver reported helmet more comfortable with valve at this position. From observation the appearances were about right; his dress properly inflated; ventilation good; telephone from diver O. K.; to diver not working.

Experimental dive No. 18, March 12, 1914.

[Diver DRELLISHAK.]

Same equipment as in previous test (experiments Nos. 16 and 17). No time taken. Helmet with valve lowered to give capacity in helmet above center line of regulating valve of 730 cubic inches. Diver compressed to 25 pounds. Pressure (56 feet). Tested valve in various positions. Three cylinders used. Diver very light, and to remain on bottom necessary to slow down pumps until ventilation in helmet was poor. Upon decompression diver reported he felt uncomfortable from bad air in helmet. From observation it is believed that, in accordance with British Admiralty report, the lower positions of the regulating valve renders breathing easier when using a limited air supply. With plenty of air flowing through the helmet, however, this condition does not apply, and that with the standard weights attached to diving dress the approximate correct position for the regulating valve in regard to height is when the center line of the valve is at such an elevation as to give a volume of about 600 cubic inches. With the suit properly adjusted, as regards inflation, and with valve nearly wide open, the ventilation of the helmet is excellent. When the diver is at rest his balance is good, and he feels comfortable; however, considerable air is wasted, and it is doubted whether or not the products of respiration are properly exhausted. Further tests will more accurately determine the correct location of the valve.

Experimental dive No. 19, March 12, 1914.

[Diver LOUGHMAN.—To try out same helmet as used in test No. 45 (experimental dive No. 18).]

	p. m.
Diver entered tank, 1 cylinder	2. 24
Cover secured	2. 26
Pressure:	
15 pounds, 2 cylinders	2. 29
30 pounds, 3 cylinders	2. 34
45 pounds	2. 34½
60 pounds, 4 cylinders	2. 36
75 pounds (168 feet)	2. 37
75 pounds, started decompression (pumps stopped)	2. 50
15 pounds, started 1 pump, 1 cylinder	2. 52
9 pounds	2. 55
5 pounds	2. 59
0 pounds	3. 02
Cover removed	3. 03
Diver called up	3. 05

Reported feeling effects of CO_2. Had slight headache. From observation, conditions same as in test No. 45 (experimental dive No. 18). During this test Siebe-Gorman telephone transmitter used by attendant enabled the diver to hear messages fairly well. Schrader phone used in helmet.

Experimental dive No. 20, March 12, 1914.

[Diver LOUGHMAN.—To try out helmet used in test No. 43, experiment No. 16.]

Same equipment as in tests Nos. 43, 44, 45, 46, experimental dives Nos. 16, 17, 18, and 19.

	p. m.
Diver entered tank, 1 cylinder	3.17
Cover secured	3.18
Pressure:	
0 pounds	3.20
15 pounds, 2 cylinders	3.25
25 pounds	3.28
5 pounds, 1 cylinder	3.28½
0 pounds	3.31

Same conditions as in experiment No. 16. Telephone same as in experiment No. 19.

Experimental dive No. 21, March 12, 1914.

[Diver ANDERSON, chief turret captain, U. S. S. *North Dakota.*]

Same purpose and with same equipment as in experiment No. 20.

Diver had no experience beyond what he had acquired during four shallow dives while attending course of instruction at diving school.

	p. m.
Entered tank, 1 cylinder	3.49
Cover secured	3.51
Pressure:	
0 pounds	3.52
15 pounds, 2 cylinders	3.55
30 pounds	3.58
40 pounds, 3 cylinders	4.00
60 pounds, 4 cylinders	4.02
75 pounds (168 feet)	4.03
75 pounds, started decompression. All pumps stopped	4.05
18 pounds, started 1 pump, 1 cylinder	4.08
15 pounds	4.10
9 pounds	4.13
5 pounds	4.18
0 pounds	4.23½
Cover removed	4.25
Diver called up	4.26

Same reports as in tests Nos. 43 and 47, experiments Nos. 17 and 20.

Upon being questioned why he took so long a time in going down under pressure, Anderson stated that the work was new to him and he did not know what to expect, but that if given another chance he could increase the speed of his compression considerably. He had been instructed to take pressure as fast as he could.

He was very nervous when he entered the tank. This feeling wore away quickly, and he was much pleased with the experience.

Special attention invited to the diver's lack of experience and the fact that he is a chief petty officer and holds certificate as a qualified diver.

Experimental dive No. 22, March 13, 1914 (Friday).

[Diver Nielson.—To try Morse commercial type of telephone in helmet, with Siebe-Gorman transmitter in use by attendant: To try balancing pressures; and to test air in dress with all pumps stopped while being decompressed.]

Morse equipment; pumps Nos. 15, 1365, and 1366 standing by.

	p. m.
Diver entered tank, 1 cylinder	2. 16
Cover secured	2. 20
Pressure:	
0 pounds	2. 25
15 pounds, 2 cylinders	2. 25¼
30 pounds, 3 cylinders	2. 25¾
45 pounds, 4 cylinders	2. 26¼
50 pounds, 5 cylinders	2. 27
75 pounds, 6 cylinders	2. 27¼

Driver inflated dress and rose slowly to surface of water; opened valve and slowly descended; repeated this performance several times, keeping perfect control of himself all the time; telephone communication good.

Started decompression; stopped all pumps	2. 36
Decompressing very slowly; pressure 22 pounds, 1 pump, 1 cylinder	2. 43
Pressure:	
17 pounds	2. 45
15 pounds	2. 48
9 pounds	2. 53
5 pounds	3. 00
0 pounds	3. 10
Cover removed	3. 13
Diver left water, condition excellent	3. 14

Experimental dive No. 23, Friday, March 13, 1914.

[Diver Crilley.—Helmet dive; temperature of water 75°. To try effect on action of helmet when using large volume of air.]

	p. m.
Entered water, 2 cylinders	3. 33
Left water; helmet flooded	3. 35
Entered water, helmet weighted with 4 lead weights suspended from each quarter of corselet; 1 cylinder at 26 revolutions	3. 43
Pressure 2 pounds, 2 cylinders	3. 45
Called up by attendant to inquire how things were operating; diver reported O. K.; pump stopped	3. 46
Entered water, pressure 2 pounds, 1 cylinder	3. 47
Pressure:	
2 pounds, 2 cylinders	3. 48
2 pounds, 3 cylinders	3. 49
2 pounds, 4 cylinders	3. 49½
2 pounds, 5 cylinders	3. 50
2 pounds, 6 cylinders	3. 50¼
2 pounds, 7 cylinders	3. 50½
2 pounds, 8 cylinders	3. 51
2 pounds; cut out six cylinders	3. 51¼
Diver called up	3. 52

Diver chilled. Reported that roar of air in helmet was terrific from 8 cylinders. The large volume of air was tried at low pressure with diving ladder shipped, life line on diver and manhole cover removed, to determine whether or not an increased air supply while being decompressed would cause helmet to lift off the diver's shoulders, with possible danger of his either being confused, injured, or of loosing the helmet and being hurt by pressure. The air from four diving pumps coupled together failed to have any effect on the helmet. With 1 cylinder air escaped from regulating valve. With more than 1 cylinder two columns of air bubbles rose from corselet, one from either shoulder. Depth of water in tank, 6 feet 10 inches.

Experimental dive No. 24, March 14, 1914.

[Divers GRAHAM, LYNCH, DURSTADT, and RILEY (U. S. S. *North Dakota*); Diver CRILLEY in charge.—To repair leaks in tank.]

Without apparatus.

	p. m.
Divers entered tank	2. 05
Pressure:	
0 pounds	2. 07
15 pounds	2. 21
25 pounds (56 feet)	2. 22
25 pounds	2. 23
5 pounds	2. 25
0 pounds	2. 30
Men called up	2. 32

While under maximum pressure, litharge cement applied from inside to leaks in tank.

Experimental dive No. 25, March 16, 1914.

[Divers CRILLEY and NIELSON.—To repair tank.]

	a. m.
Entered tank	10. 00
Cover secured	10. 05
Pressure:	
Started	10. 15
15 pounds	10. 21
20 pounds	10. 27
30 pounds	10. 32
0 pounds	11. 00

Litharge cement applied to leaks from inside tank.

Experimental dive No. 26, March 17, 1914.

[Diver DRELLISHAK.—To try out Morse telephone.]

Morse apparatus.

	p. m.
Entered water	2. 10
Diver came up; water leak in helmet	2. 14
Reentered water, 2 cylinders	2. 24
Signaled "More air;" pump speeded up	2. 28
Cover secured, 3 cylinders	2. 29
Pressure:	
Started	2. 30
15 pounds	2. 30½
30 pounds	2. 31
45 pounds, 4 cylinders	2. 31½
60 pounds	2. 32
75 pounds (168 feet)	2. 32½

	p. m.
Decompressed to—	
60 pounds; diver signaling for more air	2. 32½
52 pounds (air O. K.)	2. 33
42 pounds	2. 34
17 pounds	2. 39
13 pounds	2. 42
9 pounds	2. 45
5 pounds	2. 50
Diver left water	2. 57

Diver's condition normal; air supply from 2 pumps (4 cylinders) insufficient at 75 pounds. At maximum pressure diver gave evidence of severe distress from effects of an accumulation of CO_2. Condition not relieved until pressure had been reduced to 42 pounds (72 feet). No results from telephone. Noise in helmet excessive.

Experimental dive No. 27, March 17, 1914.

[Diver CRILLEY.—Helmet only.]

	p. m.
Entered water, 2 cylinders	3. 27
Cover secured	3. 30
Pressure:	
Started	3. 31
10 pounds	3. 31¼
15 pounds	3. 31½
20 pounds, 3 cylinders	3. 31¾
25 pounds	3. 32¼
35 pounds, 4 cylinders	3. 32¾
40 pounds, 5 cylinders	3. 33½
45 pounds, 6 cylinders	3. 33¾
50 pounds, 7 cylinders	3. 34
55 pounds	3. 34½
60 pounds (132 feet), 8 cylinders	3. 35
Decompressed to—	
13 pounds, 2 cylinders	3. 39
9 pounds	3. 42
5 pounds	3. 47
0 pounds	3. 52
Diver left water	3. 55

Diver left tank in normal condition; temperature of water 80° F. No difficulty in breathing. Less air could have been used without trouble.

Experimental dive No. 28, March 20, 1914.

[Diver GERDTS.—To try experimental phone.]

	p. m.
Entered water, 1 cylinder	2. 00
Cover secured, 1 cylinder	2. 03
Pressure:	
Started, 1 cylinder	2. 05
15 pounds, 2 cylinders	2. 09
Decompressed to 10 pounds, 2 cylinders	2. 10
Pressure:	
15 pounds, 2 cylinders	2. 10½
30 pounds, 2 cylinders	2. 13
45 pounds, 3 cylinders	2. 14½
50 pounds (112 feet), 4 cylinders	2. 15½

	p. m.
Decompressed to—	
13 pounds (stopped all pumps)	2. 25
9 pounds	2. 30
5 pounds (started 1 pump, 1 cylinder)	2. 33
0 pounds	2. 38
Left water	2. 41

Diver's condition normal; only fair results from telephone (Navy fire-control type); readjustment necessary. During decompression air supply shut off for eight minutes. Inflation of dress and air for diver maintained by utilizing expansion of air in dress during decompression. It being definitely proved that in case of an accident to a diver's air supply, and the nonreturn valve in the helmet did not fail to function, diver could be hauled up slowly from great depths without danger. If the diver was well trained and communication what it should be, decompression could even be safely affected from a severe exposure. The operation requires careful management.

Experimental dive No. 29, March 20, 1914.

[Diver Stillson.—To try maximum dive with air from 4 diving pumps.]

	p. m.
Entered water, 1 cylinder	3. 10
Pressure:	
Started, 1 cylinder	3. 14
15 pounds (33 feet), 2 cylinders	3. 16
30 pounds (66 feet), 3 cylinders	3. 20
45 pounds (99 feet), 4 cylinders	3. 21
60 pounds (132 feet), 5 cylinders	3. 21½
75 pounds (168 feet), 6 cylinders	3. 21¾
90 pounds (201 feet), 7 cylinders	3. 23
100 pounds (224 feet), 8 cylinders	3. 23¼
Stopped all pumps; decompressed to 40 pounds	3. 24
Restarted 3 cylinders	3. 26
Decompressed to—	
35 pounds, 3 cylinders	3. 28
30 pounds, 2 cylinders	3. 31
27 pounds, 2 cylinders	3. 34
22 pounds, 2 cylinders	3. 36
17 pounds, 1 cylinder	3. 39
13 pounds	3. 42
9 pounds	3. 47
5 pounds	3. 53
0 pounds	4. 08
Diver left water	4. 10

Diver experienced slight inflammation and itching sensation of the skin (first symptoms of bends); no nausea or pain. Air supply adequate up to 75 pounds pressure, when labor of pumping operation became severe. Pumpmen could not maintain speed of pumps at 100 pounds pressure and diver had to be decompressed. During first part of compression diver experienced ear troubles due to a cold. At maximum pressure diver suffered from effects of CO_2 in helmet; experienced a feeling of intoxication.

Experimental dive No. 30, March 23, 1914.

[Diver LOUGHMAN.—To try Morse telephone.]

	p. m.
Entered water, 1 cylinder	2. 18
Pressure:	
Started, 1 cylinder	2. 22
15 pounds, 1 cylinder	2. 23
30 pounds, 2 cylinders	2. 24½
45 pounds, 3 cylinders	2. 25½
60 pounds, 4 cylinders	2. 26
75 pounds (168 feet), 5 cylinders	2. 27
Decompressed to—	
17 pounds, 1 cylinder	2. 34
13 pounds, 1 cylinder	2. 38
9 pounds, 1 cylinder	2. 41
5 pounds, 1 cylinder	2. 46
0 pounds, 1 cylinder	2. 51
Diver left water	2. 52

Diver's voice could be plainly heard, but not vice versa; diver troubled by ear pains during first part of compression.

Experimental dive No. 31, Mar. 23, 1914.

[Diver FRENCH.—To experience sensations of diving.]

	p. m.
Diver entered water, 1 cylinder	3. 22
Pressure:	
Started, 1 cylinder	3. 29
15 pounds, 2 cylinders	3. 30½
30 pounds, 2 cylinders	3. 32
45 pounds, 3 cylinders	3. 33
60 pounds, 4 cylinders	3. 34
75 pounds (168 feet), 6 cylinders	3. 36
Decompressed to—	
17 pounds (diver showing signs of distress)	3. 38
13 pounds (diver sick)	3. 43½
9 pounds (diver sick)	3. 48½
0 pounds	4. 05
Diver left tank	4. 07

Diver (Passed Asst. Surg. G. R. W. French) was extremely nauseated and barely able to retain consciousness. Preparations made for recompression, to which patient objected. As he gradually began to improve his wishes were not overruled. Dr. French did not fully recover for three or four days. He attributed his indisposition to disorientation.

Experimental dive No. 32, Mar. 24, 1914.

[Diver NIELSON.—To try disconnecting and remaking air hose joints under water.]

	p. m.
Entered water, 1 cylinder	2. 31
Called up, suit leaking, 1 cylinder	2. 34
Reentered water, 1 cylinder	2. 36
Disconnected air hose, 1 cylinder	2. 38
Remade joint, 1 cylinder	2. 40
Disconnected, 1 cylinder	2. 41
Remade joint, 1 cylinder	2. 46
Broke joint, 1 cylinder	2. 51
Remade joint, 1 cylinder	2. 54

	p. m.
Pressure:	
Started, 1 cylinder	3.03
15 pounds, 2 cylinders	3.03½
30 pounds, 3 cylinders	3.09
45 pounds, 4 cylinders	3.11
50 pounds (112 feet), 5 cylinders	3.11½
Diver disconnected and reconnected air hose several times.	
Decompressed to—	
13 pounds, 1 cylinder	3.15
9 pounds, 1 cylinder	3.17
Diver removed weights	3.21
Decompressed to—	
5 pounds, 1 cylinder	3.26
0 pounds	3.27
Diver left water	3.29

It was clearly demonstrated that in case of a diver's air hose and life line becoming fouled it would be practicable to disconnect his air hose, couple on a new one, and to cut the life line. The operations could be performed by the diver himself or by a relief diver. Previous to any descent under water the nonreturn or safety valve in the helmet should be carefully tested and made to function properly.

Experimental dive No. 33, Mar. 26, 1914.

[Diver Crilley.—To try Schrader telephone.]

	p. m.
Entered water, 1 cylinder	3.06
Pressure—	
Started, 1 cylinder	3.11
15 pounds, 2 cylinders	3.13
25 pounds, 3 cylinders	3.14
45 pounds, 4 cylinders	3.15
75 pounds, 5 cylinders	3.16
85 pounds, 6 cylinders	3.17
85 pounds (188 feet), 7 cylinders	3.18
Decompressed to—	
17 pounds, 1 cylinder	3.19
13 pounds	3.24
9 pounds	3.27
5 pounds	3.32
0 pounds	3.37
Diver left water	3.40

Could hear diver, but could not make him understand.

Experimental dive No. 34.

[Diver Drellishak.—To try Schrader phone in new location.]

	p. m.
Entered water, 1 cylinder	1.56
Pressure:	
Started, 1 cylinder	2.10
15 pounds, 1 cylinder	2.12
30 pounds, 2 cylinders	2.13½
45 pounds, 3 cylinders	2.14
60 pounds, 5 cylinders	2.15
65 pounds (143 feet) 6 cylinders	2.19

	p. m.
Decompressed to—	
30 pounds, 2 cylinders	2.20
13 pounds, 1 cylinder	2.28
9 pounds	2.31
5 pounds	2.36
0 pounds	2.41
Diver left water	2.43

Diver could hear over phone only when pumps were stopped.

Experimental dive No. 35, March 27, 1914.

[Diver LOUGHMAN.—To try Schrader phone in new location.]

	p. m.
Entered water, 1 cylinder	2.57
Pressure:	
Started, 1 cylinder	3.05
15 pounds, 2 cylinders	3.07½
30 pounds, 2 cylinders	3.14
45 pounds, 3 cylinders	3.22
50 pounds, 5 cylinders	3.22½
60 pounds (132 feet), 6 cylinders	3.24
Decompressed to—	
17 pounds, 1 cylinder	3.25
13 pounds	3.30
9 pounds	3.38
5 pounds	3.43
0 pounds	3.45
Left water	3.47

Diver could be heard O. K. and could hear fairly well by placing his ear directly against the receiver which Drellishak was unable to do in No. 34.

Experimental dive No. 36, March 28, 1914.

[Divers DRELLISHAK and NIELSON.—To test air from separators; no water in tank.]

No apparatus.	a. m.
Entered tank	10.45
Pressure:	
Started	10.47
30 pounds	11.08
Decompressed to—	
5 pounds	11.10
0 pounds	11.15
Left tank	11.16

No traces of oil fumes could be detected in the air from factory compressors.

Experimental dive No. 37, March 30, 1914.

[Diver NIELSON.—To try experimental phone.]

	p. m.
Entered water	1.47
Pressure:	
Started	1.50½
75 pounds	1.58

	p. m.
Decompressed to—	
22 pounds	2.10½
17 pounds	2.18
13 pounds	2.21
9 pounds	2.26
5 pounds	2.33
0 pounds	2.43
Left water	2.44

Telephone worked O. K. Dive made by compressed air method. Air supply controlled by diver.

Experimental dive No. 38, March 31, 1914.

[Diver GERDTS.—To try experimental phone.]

	p. m.
Entered water	1.48
Pressure:	
Started	1.52
75 pounds (168 feet)	1.59
Decompressed to—	
22 pounds	2.11
17 pounds	2.15
13 pounds	2.18
9 pounds	2.23
5 pounds	2.30
0 pounds	2.40
Left water	2.41

Telephone worked O. K.

Experimental dive No. 39, March 31, 1914.

[Diver NIELSON.—To try telephone fitted with rubber earpieces.]

	p. m.
Entered water	3.06
Pressure:	
Started	3.15½
75 pounds (168 feet)	3.24
Decompressed to—	
22 pounds	3.25
17 pounds	3.30
13 pounds	3.32
9 pounds	3.35
5 pounds	3.40
0 pounds	3.45
Left water	3.47

Test very satisfactory.

Experimental dive No. 40, April 1, 1914.

[Diver NIELSON.—To try Draeger telephone.]

	a. m.
Entered water	10.50
Pressure:	
Started	10.55
50 pounds	11.03½

	p. m.
Decompressed to—	
13 pounds	11.04
9 pounds	11.09
5 pounds	11.14
0 pounds	11.17
Left water	11.19

Telephone did not operate. Upon inspection found battery weak.

Experimental dive No. 41, April 1, 1914.

[Diver Gerdts.—Experimental phone. Diver Crilley.—Siebe-Gorman phone.]

	p. m.
Crilley entered water	2.46
Gerdts entered water	2.48
Pressure:	
Started	2.53
75 pounds	3.02
Decompressed to—	
22 pounds	3.15
17 pounds	3.20
13 pounds	3.23
9 pounds	3.28
5 pounds	3.33
0 pounds	3.38
Gerdts left water	3.40
Crilley left water	3.42

Divers could not talk over phone to each other. Experimental phone O. K. Siebe-Gorman phone fair.

Experimental dive No. 42, April 2, 1914.

[Diver Drellishak.—Siebe-Gorman diving apparatus complete.]

	a. m.
Entered water	10.45
Pressure:	
Started	10.46½
80 pounds (180 feet)	10.51
Decompressed to—	
17 pounds	10.53
13 pounds	10.57
9 pounds	11.01
5 pounds	11.07
0 pounds	11.13
Left water	11.15

Dress very comfortable, more so than others; helmet larger and more comfortable; telephone only fair; breastplate poor shape, but narrower, permitting free use of arms. In general, satisfactory, except phone.

Experimental dive No. 43, April 2, 1914.

[Diver Loughman.—To try Siebe-Gorman apparatus and telephone.]

	p. m.
Entered water	2.18
Pressure:	
Started	2.23
90 pounds (201 feet)	2.34

	p. m.
Decompressed to—	
27 pounds	2. 40
22 pounds	2. 47
17 pounds	2. 50
13 pounds	2. 53
9 pounds	2. 58
5 pounds	3. 07
0 pounds	3. 17
Left water	3. 20

Same remarks as for diver No. 42.

Experimental dive No. 44, April 3, 1914.

[Diver CRILLEY.—To try Morse experimental phone.]

	p. m.
Entered water	2. 30
Pressure:	
Started	2. 42½
92.5 pounds (205 feet)	2. 53
Decompressed to—	
31 pounds	2. 55
27 pounds	2. 59
22 pounds	3. 03
17 pounds	3. 06
13 pounds	3. 12
9 pounds	3. 20
5 pounds	3. 31
0 pounds	3. 51
Left water	3. 53

Telephone worked well, but due to faulty design of head stall receivers slipped out of place and strap fell across diver's eyes, blinding him until it was removed.

Experimental dive No. 45, April 6, 1914.

[Diver STILLSON.—To try high pressure air.]

	p. m.
Entered water	2. 51
Pressure:	
Started	2. 57
15 pounds	3. 02
30 pounds	3. 04
45 pounds	3. 05½
60 pounds	3. 05½
75 pounds (slow descent due to small capacity of air compressors)	3. 07½
90 pounds	3. 08½
100 pounds	3. 10
110 pounds	3. 10½
111 pounds (249 feet)	3. 11
Decompressed to—	
40 pounds	3. 20
35 pounds	3. 27
30 pounds	3. 29½
26 pounds	3. 33
22 pounds	3. 37½
17 pounds	3. 42

Decompressed to—	p. m.
9 pounds	3.49
5 pounds	4.06
0 pounds	4.26½
Left water	4.28

Experienced slight itching irritation of skin; Siebe-Gorman telephone worked fairly well. Diver could hear only when air supply was throttled down.

Experimental dive No. 46, April 7, 1914.

[Divers DRELLISHAK and NIELSON.—Siebe-Gorman phone. To try out Siebe-Gorman double diver type telephone (British Admiralty Standard).]

	p. m.
Nielson entered water	2.03
Drellishak entered water	2.07
Pressure:	
Started	2.18
75 pounds (168 feet)	2.23
Decompressed to—	
22 pounds	2.34
17 pounds	2.39
13 pounds	2.42
9 pounds	2.47
5 pounds	2.52
0 pounds	2.59
Drellishak left water	3.02
Nielson left water	3.04

Phones only worked fairly well. Batteries carefully tested and found O. K. Much difficulty was experienced in making divers understand who was wanted on phone. Could understand divers well. Divers could only hear when air was throttled down and exhaust valves closed.

Experimental dive No. 47, April 8, 1914.

[Diver CRILLEY.—To try Siebe-Gorman telephone at high pressure.]

	p. m.
Entered water	1.50
Pressure:	
Started	1.53½
90 pounds	1.57½
100 pounds	1.59
102½ pounds	1.59½
105 pounds	1.59¾
110 pounds	2.01
Decompressed to—	
40 pounds	2.06
35 pounds	2.08
31 pounds	2.10
26 pounds	2.13
22 pounds	2.17
17 pounds	2.22
13 pounds	2.27
9 pounds	2.34
5 pounds	2.44
0 pounds	2.54
Left water	2.56

Upon all decompressions one-half time of descent counts as time at maximum pressure and allowance is made for same in decompression. By throttling down air supply fairly well. Necessary to repeat questions many times.

Experimental dive No. 48, April 8, 1914.

[Diver Loughman.—To try Siebe-Gorman apparatus and telephone.]

	p. m
Entered water	3.12
Pressure:	
Started	3.18
75 pounds	3.26
Decompressed to—	
45 pounds	3.27
30 pounds	3.28
22 pounds	3.29
17 pounds	3.30
13 pounds	3.33
9 pounds	3.36
5 pounds	3.39
0 pounds	3.44

Same as in dive No. 46.

Experimental dive No. 49, April 8, 1914.

[Divers: Dr. French, Gunner Stillson, Chief Gunner's Mate Crilley.—To try long exposure to 110 pounds pressure.]

	a. m.
Entered tank—no water—no apparatus	10.22
Pressure:	
Started	10.24
15 pounds	10.30
30 pounds	10.34
45 pounds	10.37
60 pounds	10.39
75 pounds	10.43
90 pounds	10.51
105 pounds	10.55
108 pounds	10.58
110 pounds (246 feet)	10.59
Decompressed to—	
105 pounds	11.00
75 pounds	11.06
50 pounds	11.11
40 pounds	11.17
35 pounds	11.23
31 pounds	11.34
26 pounds	11.46
22 pounds	11.58
17 pounds	12.09
13 pounds	12.20
9 pounds	12.30
5 pounds	12.45
0 pounds	1.00
Left tank	1.03

The original intention was to remain at the maximum pressure a considerable length of time. As the maximum pressure was reached Dr. French became ill and gave evidence of being in danger of losing consciousness. He was nauseated and suffered an attack of vomiting. On account of the doctor's distress pressure was lowered to 105 pounds. At the end of five minutes he showed no improvement, and pressure was reduced to 75 pounds. At end of five minutes he began to show signs of improvement, but as it was inadvisable to proceed further, decompression was ordered. After leaving tank all three men suffered slight attacks of the bends. Gunner Stillson was the most seriously affected and did not fully recover until after several hours from the time of leaving the tank.

Experimental dive No. 50, April 13, 1914.

[Diver Drellishak.—To try Schrader helmet with new spit cock.]

	p. m.
Entered water	2. 03
Pressure:	
Started	2. 06
75 pounds (168 feet)	2. 10
Decompressed to—	
17 pounds	2. 15
13 pounds	2. 18
9 pounds	2. 21
5 pounds	2. 26
0 pounds	2. 31
Left water	2. 34

Opening in spit cock had been reamed out from $\frac{3}{32}$ to $\frac{5}{16}$ inch. Increased diameter of opening through valve gave diver much better control of apparatus. Too great positive buoyance could be quickly relieved.

Experimental dive No. 51, April 14, 1914.

[Diver Loughman.—To try improved Schrader helmet.]

	p. m.
Entered water	1. 55
Pressure:	
Started	2. 07
52.5 pounds (115 feet)	2. 14
Decompressed to—	
13 pounds	2. 40
9 pounds	2. 47
5 pounds	2. 58
0 pounds	3. 14
Left water	3. 15

Shortly before decompression was started diver reported suit filling with water and signaled to be released quickly. The temperature of water was 50° F., and diver was chilled. Decompression had to be slow on account of long exposure. Diver contracted a severe cold from the exposure and refused to dive any more; leak in dress was caused by a defective joint at the rubber collar.

Experimental dive No. 53, April 15, 1914.

[Diver Nielson.—To try Schrader apparatus and experimental phone.]

	p. m.
Entered water	1. 40
Pressure:	
Started	1. 44
55 pounds (122 feet)	1. 46

	p. m.
Decompressed to—	
13 pounds	2.15
9 pounds	2.21
5 pounds	2.32
0 pounds	2.47
Left water	2.49

Same as in dive No. 52.

Experimental dive No. 54, April 15, 1914.

[Diver SCHAFER, U. S. S. *North Dakota*.—To try inexperienced diver.]

	p. m.
Entered water	3.41
Pressure:	
Started	3.44
15 pounds	3.46
60 pounds	3.49
75 pounds	3.50
82.5 pounds (184 feet)	3.51
Decompressed to—	
22 pounds	3.56
17 pounds	3.58
13 pounds	4.01
9 pounds	4.07
5 pounds	4.14
0 pounds	4.25
Left water	4.27

Diver had no previous experience beyond that acquired at the diving school. He followed instructions and experienced no difficulty.

Experimental dive No. 55, April 16, 1914.

[Diver CRILLEY.—To try maximum pressure.]

Schrader apparatus with improved helmet.

	p. m.
Entered water	2.03
Pressure:	
Started	2.18
115 pounds (258 feet)	2.23
Decompressed to—	
40 pounds	2.31
35 pounds	2.37
30 pounds	2.40
26 pounds	2.44
22 pounds	2.49
17 pounds	2.54
9 pounds	3.02
5 pounds	3.12
0 pounds	3.28
Left water	3.31

No ill effects. Apparatus functioned O. K. Telephone—no results.

Experimental dive No. 56, April 16, 1914.

[Diver SCHAFER, U. S. S. *North Dakota*.—To practice at high pressure.]

	p. m.
Entered water	3. 31
Pressure:	
Started	3. 34
75 pounds	3. 40
85 pounds	3. 45
Decompressed to—	
22 pounds	3. 45
17 pounds	3. 50
13 pounds	3. 52
9 pounds	3. 55
5 pounds	4. 01
0 pounds	4. 07

No ill effects.

Experimental dive No. 57, April 17, 1914.

[Diver NIELSON.—To try high pressure.]

Schrader suit, helmet, and telephone.

	a. m.
Entered water	10. 32
Pressure:	
Started	10. 35
15 pounds	10. 35½
30 pounds	10. 36
45 pounds	10. 37⅓
60 pounds	10. 37¾
75 pounds	10. 38
90 pounds	10. 38½
100 pounds	10. 39¼
105 pounds	10. 40
Decompressed to—	
40 pounds	10. 43
35 pounds	10. 49
26 pounds	10. 55
22 pounds	10. 59½
17 pounds	11. 05
9 pounds	11. 14
5 pounds	11. 24
0 pounds	11. 39
Diver left water	11. 42

Conditions normal.

Experimental dive No. 58, April 17, 1914.

[Diver DRELLISHAK.—To try high pressure.]

Schrader suit, helmet, and telephone.

	p. m.
Entered water	2. 05
Pressure:	
Started	2. 07
15 pounds	2. 08
110 pounds (246 feet)	2. 22¾

	p. m
Decompressed to—	
40 pounds	2.24
35 pounds	2.31
30 pounds	2.35
26 pounds	2.38
22 pounds	2.44
17 pounds	2.49
9 pounds	2.55
5 pounds	3.05
0 pounds	3.20
Left water	3.24

Condition normal.

Experimental dive No. 59, April 17, 1914.

[Diver MILLER, U. S. S. *North Dakota*.—To try high pressure.]

Morse suit, helmet, and telephone.

	p. m.
Diver entered water	3.27
Pressure:	
15 pounds	3.35
75 pounds	3.39
Decompressed to—	
17 pounds	3.39⅓
9 pounds	3.44
5 pounds	3.47
0 pounds	3.56
Diver left water	3.59

Inexperienced diver.

Experimental dive No. 60, April 20, 1914.

[Diver CRILLEY.—To try high pressure.]

Schrader suit, helmet, and telephone.

	p. m.
Entered water	2.53
Pressure:	
25 pounds	2.57
90 pounds (201 feet)	3.02
Decompressed to—	
31 pounds	3.10
26 pounds	3.14
22 pounds	3.17
17 pounds	3.20
13 pounds	3.25
9 pounds	3.32
5 pounds	3.42
0 pounds	4.02
Diver left water	4.04

Experimental dive No. 61, April 20, 1914.

[Diver GERDTS.—To try high pressure.]

Morse suit, helmet, and navy telephone.

	p. m.
Diver entered water	2.15
Pressure 15 pounds	2.23

Decompressed to—	p. m.
10 pounds	2. 23½
5 pounds	2. 24
0 pounds	2. 25
Diver left water	2. 31

Diver states that he was troubled with his ears and did not wish to dive any more. The opinion is that his trouble was due to lack of courage.

Experimental dive No. 62, April 21, 1914.

[Diver DRELLISHAK.]

Schrader suit, helmet, and telephone.	p. m.
Diver entered water	1. 55
Pressure:	
Started	1. 59
75 pounds (168 feet)	2. 03½
Decompressed to—	
18 pounds	2. 07½
13 pounds	2. 12
9 pounds	2. 15
5 pounds	2. 20
0 pounds	2. 25
Diver left water	2. 28

Experimental dive No. 63, April 21, 1914.

[Diver NIELSON.]

Morse suit, helmet, and Navy telephone.	p. m.
Entered water	2. 45
Pressure:	
15 pounds	2. 48
90 pounds (201 feet)	2. 51
Decompressed to—	
35 pounds	2. 56½
30 pounds	3. 02
26 pounds	3. 04
22 pounds	3. 07
17 pounds	3. 12
13 pounds	3. 17
9 pounds	3. 24
5 pounds	3. 35
0 pounds	3. 50
Diver left water	3. 52

Experimental dive No. 64, April 22, 1914.

[Diver CRILLEY.]

Morse suit, helmet, and Navy telephone.	p m.
Entered water	2. 23
Pressure 110 pounds (246 feet)	2. 31½
Decompressed to—	
45 pounds	2. 41
40 pounds	2. 46
35 pounds	2. 49

	p. m.
Decompressed to—	
31 pounds	2. 52
26 pounds	2. 58
22 pounds	3. 03
17 pounds	3. 13
13 pounds	3. 28
9 pounds	3. 43
5 pounds	4. 02
0 pounds	4. 24
Diver left water	4. 26

Experimental dive No. 65, April 23, 1914.

[Diver DRELLISHAK.]

Morse suit, helmet, and Navy telephone.

	p. m.
Entered water	1. 53
Pressure:	
Started	1. 57
90 pounds (201 feet)	1. 58
Decompressed to—	
35 pounds	2. 03
30 pounds	2. 05
26 pounds	2. 10
22 pounds	2. 13
17 pounds	2. 18
13 pounds	2. 24
9 pounds	2. 31
5 pounds	2. 42
0 pounds	2. 56
Diver left water	3. 00

Experimental dive No. 66, April 24, 1914.

[Diver CRILLEY.]

Morse suit, helmet, and Navy telephone.

	p. m.
Entered water	2. 02
Pressure:	
Started	2. 09
92½ pounds	2. 12
Decompressed to—	
26 pounds	2. 27
22 pounds	2. 32
17 pounds	2. 35
13 pounds	2. 40½
9 pounds	2. 47½
5 pounds	2. 58
0 pounds	3. 17
Diver left water	3. 19

Experimental dive No. 67, April 27, 1914.

[Diver DRELLISHAK.]

Morse suit, helmet, and Navy telephone.

	p. m.
Entered water	1. 55
Pressure:	
Started	2. 02
15 pounds	2. 04
75 pounds (168 feet)	2. 05
Decompressed to—	
17 pounds	2. 13
13 pounds	2. 16
9 pounds	2. 19
5 pounds	2. 25
0 pounds	2. 30
Diver left water	2. 32

Experimental dive No. 68, April 27, 1914.

[Diver CRILLEY.]

Schrader suit, helmet, and Navy telephone.

	p. m.
Entered water	2. 58
Pressure:	
Started	3. 00
15 pounds	3. 00½
75 pounds (168 feet)	$3.01\frac{4}{15}$
Decompressed to—	
17 pounds	3. 09
13 pounds	3. 12½
9 pounds	3. 15
5 pounds	3. 21
0 pounds	3. 26
Left water	3. 29

Experimental dive No. 69, April 29, 1914.

[Diver DRELLISHAK.]

Draeger self-contained diving apparatus.

	p. m.
Entered water	2. 25
Pressure:	
Started	2. 28
15 pounds	2. 29½
Decompressed to 0 pounds	3. 26½
Left water	3. 32

Cylinders empty.

Experimental dive No. 70, April 30, 1914.

[Diver Crilley.]

Siebe-Gorman self-contained apparatus.

	p. m.
Entered water	2. 11
Pressure:	
Started	2. 20
15 pounds	2. 20⅙
24 pounds	2. 20⅔
Decompressed to—	
5 pounds	2. 45⅔
0 pounds	2. 49⅔
Left water	2. 52

Cylinders empty.

Experimental dive No. 71, April 30, 1914.

[Diver Nielson.]

Siebe-Gorman self-contained apparatus.

	p. m.
Entered water	3. 25
Pressure:	
Started	3. 27
15 pounds	3. 28
24 pounds	3. 29
Decompressed to—	
5 pounds	4. 03
0 pounds	4. 08
Left water	4. 10

Pressure gauge in helmet recorded as follows: 3.27, 105 atmospheres; 3.58, 30 atmospheres; 4.01, 18 atmospheres.

Thirteen atmospheres in cylinder after dive. Phone O. K.

Experimental dive No. 71a, May 1, 1914.

[Diver Drellishak.]

Siebe-Gorman self-contained apparatus.

	p. m.
Entered water	2. 22
Pressure:	
Started	2. 32½
15 pounds	2. 33½
25 pounds	2. 34
Decompressed to—	
5 pounds	2. 56
0 pounds	3. 02
Diver left water	3. 05

Cylinders empty. Diver performed work and was much distressed.

Experimental dive No. 72, May 4, 1914.

[Diver DRELLISHAK.]

Schrader suit, helmet, and telephone.

	p. m.
Diver entered water	2.00
Pressure:	
Started	2.08⅜
15 pounds	2.08⅝
90 pounds (201 feet)	2.10⅛
Decompressed to—	
23 pounds	2.19 11/12
17 pounds	2.24
13 pounds	2.27
9 pounds	2.32
5 pounds	2.39
0 pounds	2.49
Diver left water	2.54

Experimental dive No. 73, May 5, 1914.

[Diver STILLSON.]

Morse suit, helmet, and Navy telephone.

	p. m.
Entered water	2.45
Pressure:	
Started	2.49
15 pounds	2.49¼
74 pounds	2.54¼
Decompressed to—	
22 pounds	3.01
17 pounds	3.05
13 pounds	3.08
9 pounds	3.13
5 pounds	3.20
0 pounds	3.30
Diver left water	3.34

Experimental dive No. 74, May 7, 1914.

[Divers NIELSON, using Siebe-Gorman self-contained apparatus; STILLSON, using Morse suit, helmet, and Navy telephone.]

	p. m.
Entered water	2.46
Pressure:	
Started	2.56
15 pounds	2.57
75 pounds (168 feet)	2.58½
Decompressed to—	
52 pounds	3.00
30 pounds	3.03⅛
17 pounds	3.04
13 pounds	3.06
9 pounds	3.09
5 pounds	3.14
0 pounds	3.19
Divers left water	3.22

Experimental dive No. 75, May 8, 1914.

[Divers CRILLEY, using Morse suit, helmet, and Navy telephone; STILLSON, using Siebe-Gorman self-contained apparatus.]

	p. m.
Crilley entered water	2. 10
Stillson entered water	2. 16
Pressure:	
Started	2. 20
15 pounds	2. 21
90 pounds (201 feet)	2. 22
Decompressed to—	
26 pounds	2. 31
22 pounds	2. 36
17 pounds	2. 38
13 pounds	2. 43
9 pounds	2. 48
5 pounds	2. 55
0 pounds	3. 05
Divers left water	3. 09

Experimental dive No. 76, May 12, 1914.

[Divers: DRELLISHAK, Morse suit, helmet, and Navy telephone; STILLSON, Schrader suit, helmet, and telephone.]

	p. m.
Drellishak entered water	2. 50
Stillson entered water	2. 52
Pressure:	
Started	2. 54
15 pounds	2. 54$\frac{1}{12}$
52½ pounds	2. 54$\frac{59}{60}$
Decompressed to—	
13 pounds	3. 25
9 pounds	3. 32
5 pounds	3. 42
0 pounds	3. 57
Divers left tank	3. 59

One-half hour exposure.

Experimental dive No. 77, May 13, 1914.

[Divers: NIELSON, Morse suit, helmet, and Navy telephone; STILLSON, Schrader suit, helmet, and telephone.]

	p. m.
Nielson entered water	2. 25
Stillson entered water	2. 30
Pressure:	
Started	2. 34$\frac{1}{12}$
60 pounds (132 feet)	2. 34$\frac{11}{12}$
Decompressed to—	
13 pounds	3. 05
9 pounds	3. 14
5 pounds	3. 27
0 pounds	3. 47
Divers left water	3. 49

One-half hour exposure.

Experimental dive No. 78, May 14, 1914.

[Divers: **Drellishak**, Schrader suit, helmet, and Navy telephone; **Crilley**, Morse suit, helmet, and Navy telephone.]

	p. m.
Drellishak entered water	1. 53
Crilley entered water	2. 00
Cover secured	2. 04
Pressure:	
Started	2. 08
15 pounds	2. 08$\frac{1}{4}$
70 pounds	2. 09$\frac{2}{3}$
Decompressed to—	
25 pounds	2. 39$\frac{2}{3}$
20 pounds	2. 45
11 pounds	2. 48$\frac{1}{2}$
9 pounds	3. 04
5 pounds	3. 19
0 pounds	3. 19$\frac{5}{12}$
Divers left water	3. 39$\frac{3}{8}$

One-half hour exposure.

Experimental dive No. 79, May 15, 1914.

[Divers: **Nielson**, Schrader suit, helmet, and Navy telephone; **Crilley**, Morse suit, helmet, and Navy telephone.]

	p. m.
Nielson entered water	2. 10
Crilley entered water	2. 20
Pressure:	
Started	2. 22$\frac{1}{2}$
15 pounds	2. 22$\frac{2}{3}$
80 pounds	2. 24$\frac{5}{6}$
Decompressed to—	
27 pounds	2. 50
22 pounds	2. 54$\frac{5}{6}$
18 pounds	2. 57
13 pounds	3. 00$\frac{11}{30}$
9 pounds	3. 10$\frac{1}{3}$
5 pounds	3. 25$\frac{2}{3}$
0 pounds	3. 50$\frac{2}{3}$
Divers left tank	3. 54

Twenty-five minutes exposure.

Experimental dive No. 80, May 21, 1914.

[Divers: **Drellishak**, Schrader suit, helmet, and Navy telephone; **Crilley**, Morse suit, helmet, and Navy telephone.]

	p. m.
Drellishak entered water	1. 44
Crilley entered water	1. 55
Pressure:	
Started	1. 57
15 pounds	1. 57$\frac{1}{12}$
90 pounds	2. 04

Decompressed to—	p. m.
31 pounds	2.26
27 pounds	2.32
22 pounds	2.37
18 pounds	2.42
13 pounds	2.52½
9 pounds	3.02½
5 pounds	3.02 7/12
0 pounds	3.52⅔
Divers left tank	3.54

Experimental dive No. 81, May 25, 1914.

[Diver DRELLISHAK.]

Schrader suit, helmet, and Navy telephone.	p. m.
Entered water	2.20
Pressure:	
Started	2.26
15 pounds	2.26 1/10
110 pounds	2.34½
Decompressed to—	
35 pounds	2.38
31 pounds	2.40
27 pounds	2.44
22 pounds	2.47
18 pounds	2.50
13 pounds	2.55
9 pounds	3.02
5 pounds	3.12
0 pounds	3.27
Diver left water	3.30

Experimental dive No. 82, June 1, 1914.

[Diver DRELLISHAK.]

Draeger submarine escape apparatus.

The diver inflated the breathing bag and entered water. No pressure used. The apparatus kept diver afloat near the surface of the water; air only was used in the cylinders, and after a few minutes it was noticed that diver did not answer signals. The color of his face was abnormal and he was given a signal to come up (by touching his hand), and when he failed to reply was immediately hauled up; he was found unconscious and suffering from lack of oxygen. After the apparatus was removed the diver recovered quickly.

Experimental dive No. 83, June 2, 1914.

[Diver DRELLISHAK.]

Siebe-Gorman self-contained diving apparatus.

The apparatus operated satisfactorily.

Experimental dive No. 84, June 3, 1914.

[Diver CRILLEY.]

Siebe-Gorman self-contained diving apparatus.

He remained in the water for 30 minutes. No pressure. At end of that time diver took a sample of air for analysis.

The apparatus operated satisfactorily.

Experimental dive No. 85, June 4, 1914.

[Diver CRILLEY.]

Siebe-Gorman self-contained apparatus.

	p. m.
Entered water	2. 15
Pressure:	
Started	2. 18½
25 pounds (56 feet)	2. 27
Decompressed to—	
5 pounds	2. 30
0 pounds	2. 35
Diver left water	2. 42

Diver at rest during dive. Evidence of abnormal pressure of CO_2.

Experimental dive No. 86, June 4, 1914.

[Diver DRELLISHAK.]

Draeger self-contained apparatus.

	p. m.
Entered water	3. 04
Pressure:	
Started	3. 09
15 pounds	3. 10
Decompressed to—	
5 pounds	3. 30
0 pounds	3. 37
Diver left water	3. 39

Diver performed hard work and was much distressed.

Experimental dive No. 87, June 5, 1914.

[Diver DRELLISHAK.]

Schrader suit, helmet, and Navy telephone.

	p. m.
Entered water	1. 44
Pressure:	
Started	1. 46⅚
15 pounds	1. 47
105 pounds	1. 49½
Decompressed to—	
35 pounds	1. 51
27 pounds	1. 52
22 pounds	1. 56
18 pounds	1. 59
13 pounds	2. 04
9 pounds	2. 11
5 pounds	2. 21
0 pounds	2. 41
Diver left water	2. 44

Condition: Slight symptoms of inflammation of skin.

Experimental dive No. 88, June 5, 1914.

[Diver Crilley.]

Siebe-Gorman self-contained apparatus.

	p. m.
Entered water	3.15
Pressure:	
Started	3.17½
15 pounds	3.20⅛
Decompressed to 0 pounds	3.28
Left water	3.33

Performed work and suffered slightly from effects of CO_2.

Experimental dive No. 89, June 8, 1914.

[Diver Nielson.]

Draeger self-contained apparatus.

	p. m.
Entered water	1.44
Pressure:	
Started	1.51
15 pounds	1.56
17.5 pounds	2.20
20 pounds	2.21
Decompressed to—	
15 pounds	2.24
9 pounds	2.49
Diver left water	2.53

Condition: Diver very warm and showed signs of effects of CO_2, but there were no ill effects.

Experimental dive No. 90, June 8, 1914.

[Diver Drellishak.]

Draeger submarine escape apparatus.

Diver remained under water for 10 minutes; he had perfect control of himself and the apparatus during the test.

The water was lowered and another man put in the tank ready to help him in case of an emergency.

Experimental dive No. 91, June 9, 1914.

[Diver Crilley.]

Siebe-Gorman self-contained diving apparatus.

	p. m.
Entered water	2.13
Pressure:	
Started	2.15
15 pounds	2.21
35 pounds	2.22½
Decompressed to 0	2.32½
Diver left water	2.36

Diver at rest; no ill effects.

Experimental dive No. 92, June 9, 1914.

[Diver NIELSON.]

Schrader suit, helmet, and Navy telephone.

	p. m.
Entered water	3.01
Pressure:	
Started	3.11
15 pounds	3.11$\frac{7}{60}$
100 pounds (224 feet)	3.12$\frac{1}{3}$
Decompressed to—	
31 pounds	3.20
27 pounds	3.21
22 pounds	3.23
18 pounds	3.25
13 pounds	3.31
9 pounds	3.36
5 pounds	3.46
0 pounds	3.56
Left water	4.00

Diver suffered from irritation of skin.

Experimental dive No. 94, June 10, 1914.

[Diver DRELLISHAK.]

Siebe-Gorman self-contained diving apparatus (noninjector).

	p. m.
Entered water	2.00
Pressure:	
Started	2.15
35 pounds	2.17
Decompressed to 22 pounds	2.23
Pressure, 35 pounds	2.27
Decompressed to 0 pound	2.40
Pressure, 0 pound	2.42
Left water	2.45

Diver performed hard work and was much distressed in five minutes.

Experimental dive No. 95, June 10, 1914.

[Diver CRILLEY.]

Siebe-Gorman self-contained diving apparatus (injector type).

	p. m.
Entered water	2.56
Pressure:	
Started	2.16$\frac{5}{6}$
15 pounds	3.18$\frac{1}{3}$
Decompressed to 0 pound	3.26
Diver left water	3.30

Diver performed hard work and was much distressed in five minutes.

Experimental dive No. 96, June 11, 1914.

[Diver Nielson.]

Draeger self-contained diving apparatus.

Diver remained under water for 30 minutes. He performed work by lifting and carrying a box containing 80 pounds pig lead before taking air sample.

No pressure on tank. Evidence of CO_2.

Experimental dive No. 97, June 12, 1914.

[Diver Drellishak.]

Siebe-Gorman self-contained diving apparatus.

Drellishak made dive to test air delivery at 17-pound pressure and found that the supply is insufficient when diver is performing hard work. He lifted box weighing about 90 pounds, but could only do this in spells of three minutes. As soon as the rate of breathing was increased the supply became inadequate, and excess of CO_2 was noticed, which produced severe panting and headache. This test indicates that the apparatus in its present condition is useful only for very light work.

Experimental dive No. 98, June 17, 1914.

[Diver Drellishak, Divers Crilley and Damon assisting.]

Draeger submarine escape apparatus.

	p. m.
Entered tank	2.25
Pressure:	
Started	2.35
25 pounds	2.37
75 pounds	2.45
Decompressed to—	
25 pounds	2.46
22 pounds	2.50
18 pounds	2.52
13 pounds	2.56
9 pounds	3.01
5 pounds	3.08
0 pounds	3.16
Left tank	3.22

In this test the pressure was raised to 75 pounds. Test of apparatus made during decompression Diver adjusted the helmet and used same for 28 minutes until oxygen gave out. No trouble of any kind. Two men in the tank to assist him in case of an emergency. No water in tank.

Experimental dive No. 99, June 18, 1914.

[Diver Crilley.]

Siebe-Gorman self-contained diving apparatus (noninjector).

	p. m.
Entered water	1.48
Pressure:	
Started	1.50
15 pounds	1.52
35 pounds (78 feet) (first dive)	1.52⅔
Decompressed to 0 pounds	1.57
Diver left water	2.00

Shortly after diver was secured he discovered that both the oxygen and air tanks he was using for air supply had only been partly charged. Diver was called up and new cylinders fitted to the apparatus. During second dive he remained in water 53 minutes but was able to work only in short spells.

	p. m.
Entered water	2. 13
Pressure:	
Started	$2.15\frac{1}{3}$
15 pounds	$2.17\frac{1}{6}$
35 pounds (78 feet) (second dive)	$2.17\frac{5}{6}$
Decompressed to—	
10 pounds.	
5 pounds	$2.28\frac{2}{3}$
0 pounds	$3.01\frac{1}{6}$
Diver left water	3. 06

Experimental dive No. 100, June 19, 1914.

[Diver DRELLISHAK.]

Draeger submarine escape apparatus.

	p. m.
Entered water	2. 39
Pressure:	
Started	$2.44\frac{2}{3}$
15 pounds	2. 45
75 pounds	$2.49\frac{5}{12}$
Decompressed to—	
17 pounds	$2.54\frac{1}{6}$
13 pounds	$2.57\frac{1}{2}$
9 pounds	$3.00\frac{1}{2}$
5 pounds	3. 06
0 pounds	3. 11
Diver left water	3. 14

During this test the water was lowered to 5 feet 10 inches. On decompression Drellishak adjusted the apparatus and submerged himself; he remained under water for about 15 minutes. No trouble was experienced.

Experimental dive No. 101, June 26, 1914.

[Diver CRILLEY.]

Draeger self-contained diving apparatus.

	p. m.
Entered water	1. 46
Pressure:	
Started	1. 50
15 pounds	$1.54\frac{2}{3}$
Decompressed to 0 pounds	2. 48
Diver left water	2. 50

Conditions as in previous tests.

U. S. "Walke," off Eatons Point, October 28, 1914.

[Diver NIELSON.]

Depth, 171 feet; temperature of water, 61° F.
Moderate sea; velocity of tide, 1.3 knots.
Moderate breeze from SSW. by W.

	p. m.
Entered water	1.07
Reached bottom	1.10
Called up	1.22
Left bottom	1.23
Reached—	
50 feet	1.30
40 feet	1.37
30 feet	1.41
20 feet	1.51
10 feet	2.09
Left water	2.25

Time on bottom, 13 minutes.

Time under water, 78 minutes.

Time of decompression, 62 minutes.

On the descent the diver found the descending line tending at a considerable angle but he continued the descent. He found the weight off the bottom and telephoned to have it lowered. The line was slacked off several fathoms, but the weight (100 pounds) refused to remain on bottom. The diver left weight and went to bottom keeping hold of distance line. He then found that weight was moving rapidly through water and felt the effect of the tide. During this time the ship had swung over the diver and all lines were foul under the bottom of the ship. Air was being taken from a partly charged torpedo air flask, and as the supply was running low the compressor was started. The ship veered to the wind a little and enabled the tender to get in some of the slack hose (300 feet had been paid out) and partly clear it. The diver was then called up and he made the ascent, at least part of it, at a considerable inclination from the vertical.

The wind and sea had increased to such an extent that diving from a sailing launch would have been impossible. The diver arrived on deck in normal condition. Considering the depth of water and the adverse weather conditions this dive is regarded as a remarkable one.

U. S. S. "Walke," The Race, Long Island Sound, November 3, 1914.

[Diver DRELLISHAK.]

Depth, 274 feet; temperature of water, 58° F.

Sea moderate; ebb tide, 2 knots.

Weather clear and cool. Light breeze.

	a. m.
Entered water	11.28
Reached bottom	11.35
Called up	11.39½
Left bottom	11.40
Reached—	
80 feet	11.45
70 feet	11.48
60 feet	11.52
50 feet	11.57
40 feet	12.03
30 feet	12.11
20 feet	12.18
10 feet	12.28
Left water	1.00

On the descent diver lost a little time getting clear of Jacob's ladder, the bottom rung of which was 80 feet under water and stopped to descending line. At a depth of about 200 feet diver telephoned for more air. Pressure on surface gauge raised from 150 pounds per square inch to about 175 pounds per square inch. Diver's descent was halted when he signalled for more air and he was started toward the surface slowly. At end of about 3 minutes he telephoned "O. K.," "Lower," and "Air all right," and then descended rapidly to the descending line weight, which he found off the bottom. Diver and weight lowered to bottom. Diver reported that when he neared bottom the tide suddenly became very strong. Diver moved around on bottom and collected a quantity of pebbles and a small rock covered with coral growth.

On account of the treacherous currents at "The Race" and the unreliability of the strength of the ship's low pressure air line, diver was called off the bottom at end of five minutes. He made the ascent to the bottom rung on Jacob's ladder (80 feet from surface) steadily and without difficulty. As the depth was greater than any with which we had had experience, extra time, especially at 10-foot stage, was taken for decompression. Diver arrived on deck in normal condition; no ill effects. The exact location of dive was fixed by cross bearings—"Race Rock Light"—81° true—distance, 5,575 yards. "Little Cull light"—179° true—distance, 3,700 yards. The true depth was ascertained by means of a length of piano wire and a 32-pound lead. The sounding wire was vertical when lead was on bottom. A mark was made at water's edge and the sounding measured with a steel tape line as the sounding wire was reeled in. This sounding was carefully checked by several soundings with a special hand-lead (32-pound) line. Hand-lead line measured and checked with a tape line. Soundings taken by Ensign F. M. Collier, United States Navy, assisted by ship's quartermasters and under the personal direction of the commanding officer, Lieut. (Junior Grade) L. F. Thibault, United States Navy. Bottom was hard and covered with gravel. The time occupied by diver in actually descending was two minutes. The total time diver was in depths over 100 feet was approximately 15 minutes.

Total time of descent, 7 minutes.

Total time on bottom, 5 minutes.

Total time of ascent, 1 hour 20 minutes.

Total time under water, 1 hour 32 minutes.

Air pressure corresponding to the depth of 274 feet was 8.3 atmosphere (121 pounds per square inch) excess pressure by gauge, or 9.3 atmospheres (135.7 pounds per square inch) absolute.

The exact depth of water was 273 feet 10½ inches.

Descending line, 3-inch manila rope.

Descending weight, 332 pounds.

Due to effects of tide descending line weight kept lifting off bottom. While diver was down ship kept yawing through an arc of about 16°. Reducing valve on low-pressure air line was set to operate at 170 pounds pressure at commencement of dive and later changed to operate at 200 pounds pressure. The drop in pressure at diving hose connection at first setting of reducing valve was 20 pounds. At second setting of reducing valve the drop was 25 pounds. The loss in delivery of air at the diver's helmet, due to friction in the air line and hose was considerable. It is estimated that the air pressure at the diver's control valve was less than 30 pounds in excess of the water pressure at 274 feet. The volume of free air passing through the helmet at 274 feet is estimated to have been 40 cubic feet per minute (more than the capacity of the ship's torpedo air compressor).

Previous to the descent the precaution had been taken to connect two fully charged torpedo air flasks to the air line in addition to the torpedo air compressor. These flasks have a capacity of 11 cubic feet each at 2,100 pounds pressure per square inch. During the dive the pressure in the two flasks dropped 500 pounds. On the ascent, when the diver reached shallower water, the pressure in the flasks commenced to gain, and before the diver left the water was again at 2,100 pounds. The air compressor was then stopped and air supplied from the flasks.

All signals to diver were by telephone. The diver estimates that he lost the sunlight and passed into darkness at about 150 feet from the surface and reported that the only discomfort he experienced during the dive was due to warm air and that was not excessive.

U. S. S. "Walke," off Roanoke Point, L. I., October 23, 1914.

[Diver CRILLEY.]

Depth, 90 feet; temperature of water, 62° F.

Sea smooth; ebb tide, ½ knot.

	p. m.
Entered water	2.34
Reached bottom	2.36
Left bottom	2.58½
Reached—	
20 feet	3.01
10 feet	3.06
Surface	3.16½
Left water	3.17

Time on bottom, 22½ minutes.

Time under water, 43 minutes.

Total decompression, 18 minutes.

Diver walked around on bottom. No light on bottom, which was of soft gray mud.

U. S. S. "Walke," off Roanoke Point, L. I., October 23, 1914.

[Diver NIELSON.]

Depth, 90 feet; temperature of sea water, 62° F.

Sea smooth; ebb tide, ½ knot.

	p. m.
Entered water	1.48
Reached bottom	1.49
Started up	2.05
Reached—	
20 feet	2.08
10 feet	2.11½
Left water	2.17

Time on bottom, 16 minutes.

Time under water, 29 minutes.

Total decompression, 12 minutes.

Diver walked around on bottom, which was soft gray mud.

U. S. S. "Walke," off Roanoke Island, L. I., October 23, 1914.

[Diver ANDERSON (diver navy yard, New York).]

Depth, 90 feet; temperature of water, 62° F.

Sea smooth; ebb tide, ½ knot.

	p. m.
Entered water	3.34
Reached bottom	3.37
Left bottom	4.01
Reached—	
20 feet	4.04
10 feet	4.09½
Left water	4.24

Time on bottom, 24 minutes.

Time under water, 50 minutes.

Total decompression, 23 minutes.

Diver walked around on bottom; no light. Diver brought up a piece of kelp to surface.

Note.—Anderson is an expert and skillful diver. First experience at diving with air furnished by other than hand-driven diving pumps. He stated that the experience was a revelation to him and that at this depth he felt more comfortable than when diving in the shallow water of New York Navy Yard, and using a hand pump. It was the first time he had ever used a telephone under water successfully and the efficiency of the new diving telephone was a surprise to him.

U. S. S. "Walke," off Roanoke Point, L. I., October 26, 1914.

[Diver Crilley.]

Depth 136½ feet; temperature of water 62° F.

Sea choppy; ebb tide ½ knot.

	p. m.
Entered water	1.57½
Reached bottom	2.00½
Left bottom	2.20½
Reached—	
40 feet	2.25
30 feet	2.27
20 feet	2.33
10 feet	2.43
Left water	2.58

Time on bottom 20 minutes.

Time under water 60½ minutes.

Total time of decompression 37½ minutes.

Diver on the ascent overshot the first stop by 20 feet, but descended within one minute's time to first stop of 40 feet.

Small whitecaps, wind southwest, force 3; no light on bottom, which was of soft gray mud. Diver walked around on bottom, holding onto distance line.

U. S. S. "Walke," off Roanoke Point, L. I., October 26, 1914.

[Diver Anderson (diver, navy yard, New York).]

Depth 136½ feet; temperature of water 63° F.

Sea choppy; ebb tide ½ knot.

	p. m.
Entered water	3.17
Reached bottom	3.19
Left bottom	3.26
Reached—	
40 feet	3.28
30 feet	3.29
20 feet	3.33
10 feet	3.39
Left water	3.45

Time on bottom 7 minutes.

Time under water 28 minutes.

Total decompression 19 minutes.

Small whitecaps, wind southwest, force 3; no light on bottom, which was of soft mud. Diver walked around on bottom, holding onto distance line.

U. S. "Walke," off Roanoke Point, L. I., October 26, 1914.

[Diver DRELLISHAK.]

Sea choppy; temperature of water 63° F.

Depth 136½ feet; ebb tide ½ knot.

	p. m.
Entered water	4.01½
Reached bottom	4.02½
Left bottom	4.25
Reached—	
40 feet	4.26
30 feet	4.29
20 feet	4.34
10 feet	4.44
Left water	4.57

Time on bottom 22½ minutes.

Time under water 55½ minutes.

Total decompression 32 minutes.

Small whitecaps, wind from the southwest, force 3. Air hose lowered faster than diver, and when he landed found himself foul in coils of same, which he cleared without difficulty. No light on bottom, which was of soft gray mud. Diver walked around on bottom.

U. S. S. "Walke," off Orient, L. I., October 22, 1914.

[Diver DRELLISHAK.]

Depth 84 feet; temperature of water 62° F.

Sea smooth; ebb tide 3.1 knots.

	p. m.
Entered water	2.30
Reached bottom	2.35
Called up	2.40
Left bottom	2.41
Left water	2.51

Descending line weighted with 80-pound weight. Weight landed about 30 feet abaft diving ladder. Diver had trouble in getting down. Weight swept off bottom by tide. Diver telephoned that he was on weight but not on bottom. Lowered weight and diver to bottom; landing them several feet farther abaft ladder. Diver reported that weight was lifting off bottom which was of smooth hard sand covered with white pebbles. Diver called up. The ascent due to the trend of the descending line was made at a considerable angle. The rule for diving in a tideway is that when a 50-pound weight is swept off the bottom by the tide, diving operations are impracticable. In this case an 80-pound weight would not remain on bottom. The drag on the air hose and telephone cable (stopped together) was considerable. No life line or signal line was used. Diver was not distressed by effects of tide, and with a special underwater rig could have remained under water indefinitely. Light on bottom fair; having appearance of dense shade. Due to the short decompression, the precaution was taken to place diver in recompression chamber immediately upon his arrival on deck. Pressure was applied and decompression then accomplished in the regular manner.

U. S. S. "Walke," off Roanoke Point, L. I., October 23, 1914.

[Diver STILLSON.]

Depth 88½ feet; temperature of sea water 62° F.

Sea smooth; ebb tide one-half knot.

	a. m.
Entered water	11.41
Reached bottom	11.44½
Left bottom	12.00

Reached—	p. m.
20 feet	12. 04½
10 feet	12. 07½
Left water	12. 15

Time on bottom 15½ minutes.

Time under water 34 minutes.

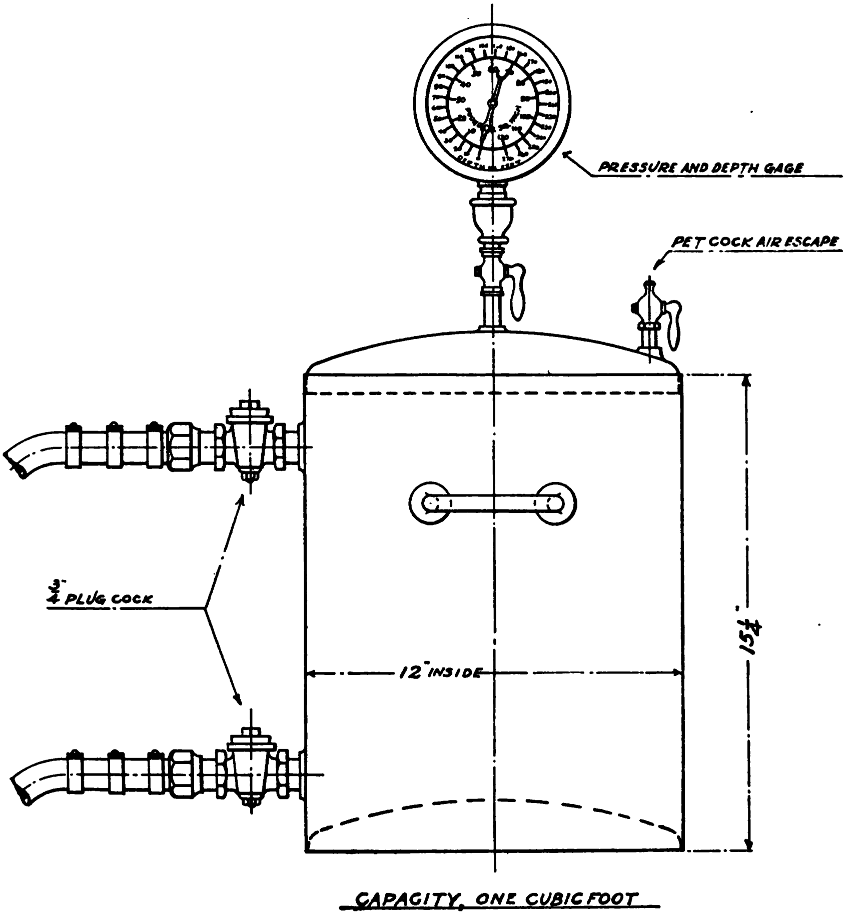
Total decompression 15 minutes.

No light on bottom which was of soft gray mud.

[Inclosure (S).]

Description of Test Tank for Diving Apparatus.

1. Steel tank; capacity, 1 cubic foot; tested to 300 pounds pressure per square inch; portable; fitted with gauge, relief valve, and suitable air-hose connections.
2. To be used in proving efficiency of diving air pumps, as a reservoir, etc.



TESTING TANK FOR DIVING APPARATUS

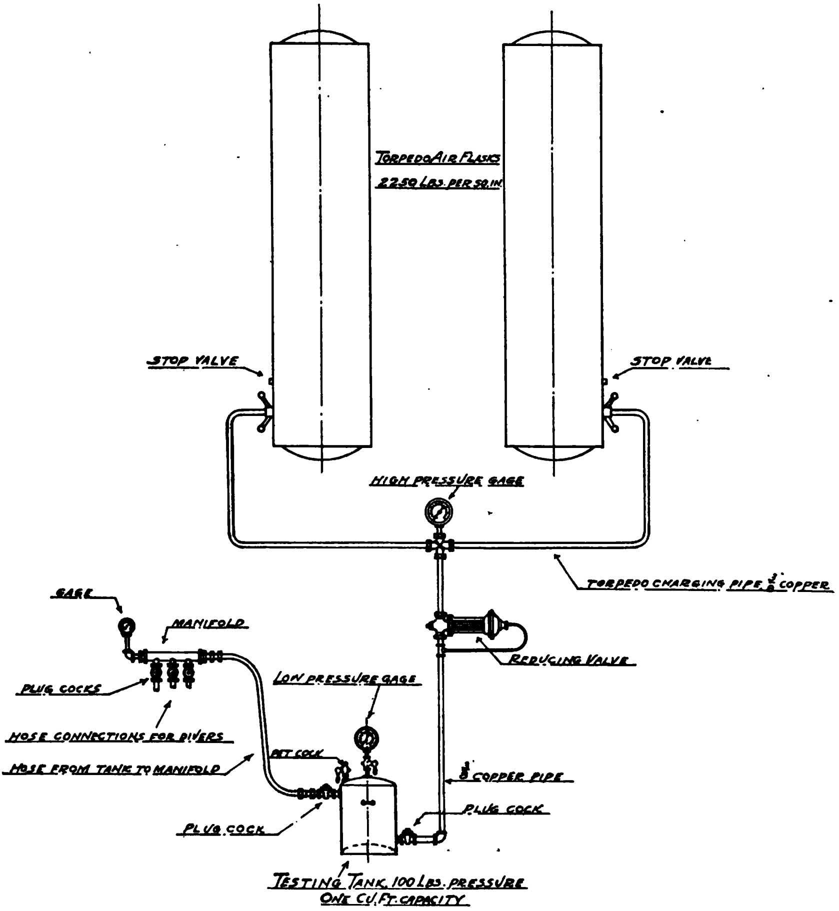
[Inclosure (T).]

Description of Diving Ladder.

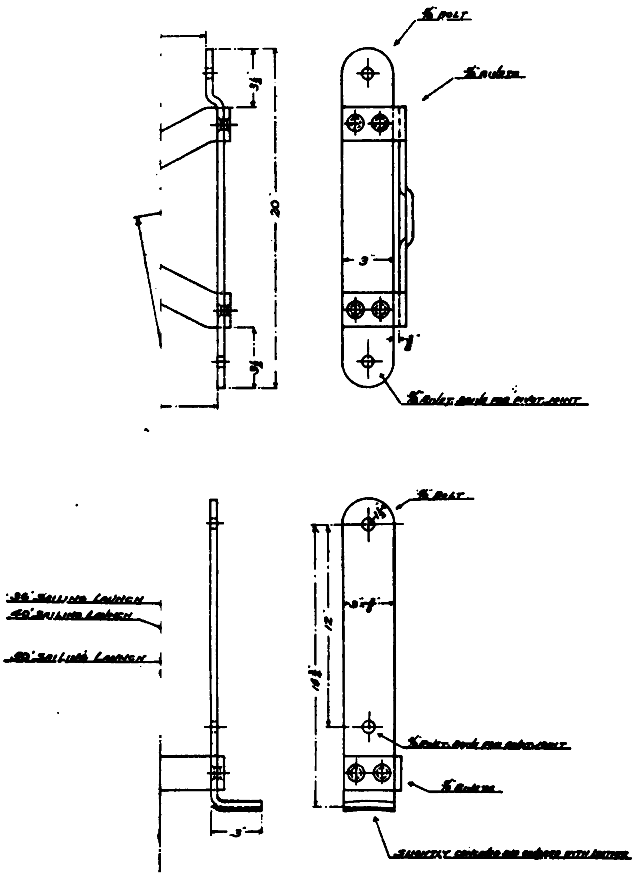
The ladder is designed to be shipped over side of Navy sailing launch and to be supported by rope lashings. The struts and braces are adjustable to different sizes of boats and the whole arrangement is made up neatly for convenience in handling and stowage.

To ship ladder in place.—Place ladder horizontally on gunwale; ship struts and braces in position and have them pointing upwards; secure a tricing line on each corner of ladder; lower ladder horizontally under boat; slack off on inboard lines; slack off lines on foot of ladder and, at same time, take in slack of both upper lines; place ladder in position and secure; haul bottom lines in to sides of ladder. To take ladder in reverse operation. If instructions are followed gunwale and side of boat will not be injured.

The ladder provides a convenient rest for diver and a means of entering and leaving the diving launch without difficulty, thus saving him from exhaustion of strenuous effort in climbing a poorly constructed ladder.



METHOD OF TAKING AIR FROM TORPEDO AIR FLASKS TO DIVERS



BOLT
RIVETS
20
3"
BOLT, BORE FOR PIVOT JOINT
BOLT
36' SAILING LAUNCH
40' SAILING LAUNCH
50' SAILING LAUNCH
12
3"
BOLT, BORE FOR PIVOT JOINT
RIVETS
SLIGHTLY CONCAVE AND COVERED WITH LEATHER

LADDER FOR DIVING APPARATUS

[Inclosure (U).]

DESCRIPTION OF METHOD OF ARRANGEMENT OF AIR FLASKS, CONNECTIONS, ETC., FOR SUPPLYING AIR TO DIVERS.

1. The general scheme as indicated.

2. Between the flasks and inlet of reducing valve, flexible high-pressure copper piping of ⅜ inch inside diameter must be used. From the low-pressure side or outlet of reducing valve diving air hose may be used.

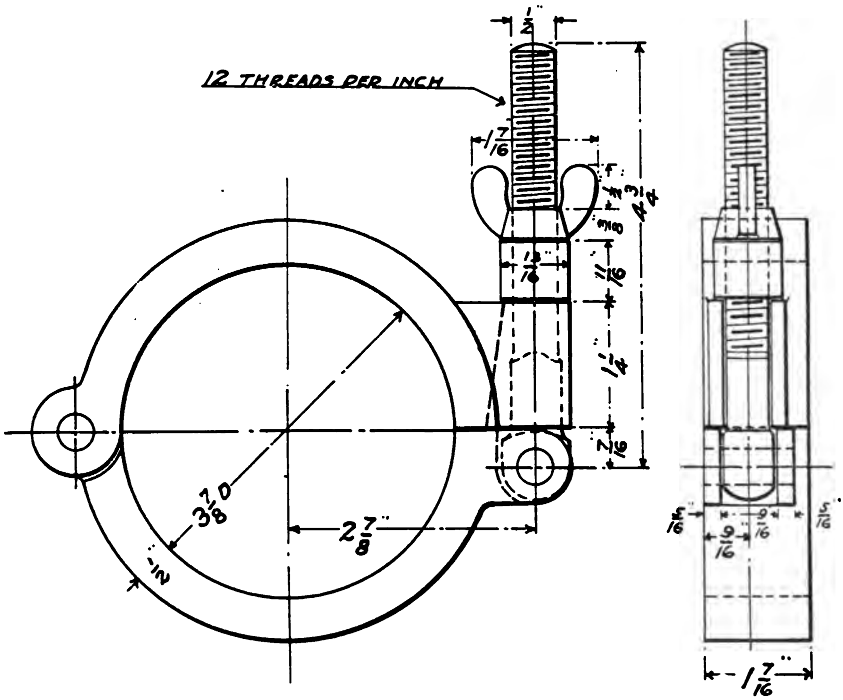
3. For details of operation see reference (a), and paragraphs 49 to 53, 151 to 157, and 208 to 212 of the report 67–T.

[Inclosure (V).]

DESCRIPTION OF TOOL FOR ASSEMBLING PISTONS OF DIVING PUMPS.

This tool facilitates the operation of replacing assembled pistons in the cylinders of diving pumps.

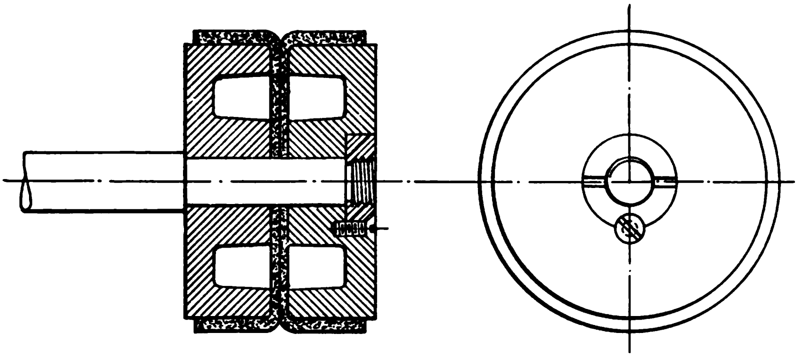
The springs under cup leathers expand the edges of the cup leathers to a greater circumference than the pump cylinders.



TOOL FOR ASSEMBLING PISTONS OF DIVING PUMPS

The purpose of the tool is to compress the cup leathers and springs until same can be entered in its cylinder. The tool is then removed and piston can be easily forced into position.

By the aid of clamp the edges of piston leathers are not injured and the operation of placing them in cylinders is made easy.



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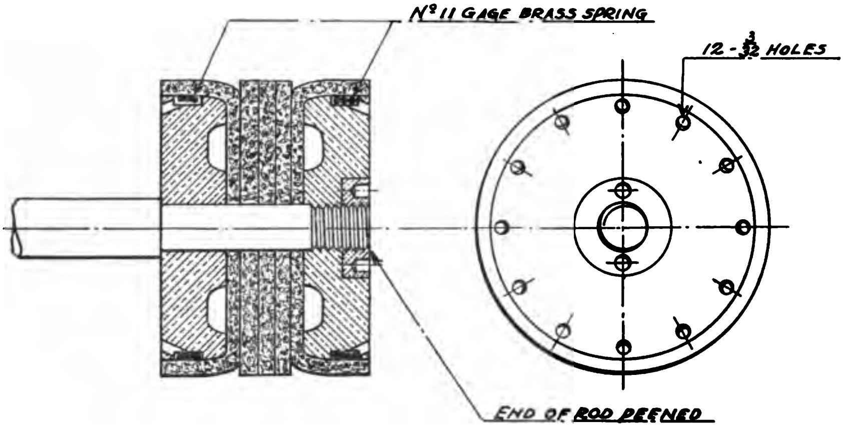


(MORSE)

SERVICE PUMP PISTONS FOR DIVING APPARATUS

[Inclosure (W).]

HANDBOOK FOR SEAMEN GUNNERS—MANUAL FOR DIVERS.

CHAPTER I.

REQUIREMENTS FOR DIVERS.

Before men are detailed for diving, they should be examined as to their fitness by a medical officer. As this is sometimes impracticable the following list of requirements and of physical defects which should cause the rejection of men having them is given for the benefit of those who may be called upon to select candidates for this employment. Divers are—

1. To be cool-headed, calm, and of a phlegmatic temperament.
2. To be in good health, have a strong constitution, and the action of the lungs to be normal.
3. Not to be short-necked, full-blooded, or with a tendency to nosebleed.
4. Not to have bloodshot eyes, or a high color on the cheeks, caused by the interlacement of numerous small but distinct blood vessels.
5. Not to be very pale, nor have lips more blue than red, nor be subject to cold hands or feet.
6. Not to perspire freely.
7. Not to be affected with cough, asthma, or catarrh.
8. Not to be subject to headaches or dizziness, or affected with deafness.
9. Not to be hard drinkers, nor have suffered frequently with venereal disease, or have had sunstroke or rheumatism.
10. Not to have been subject to palpitation of the heart or fainting spells.
11. Not at any time to have spat or coughed up blood.

Men who have long trunks with well developed chests and loins generally make good divers.

DESCRIPTION OF DIVING APPARATUS.

The essential parts of the diver's outfit consist of—

1. The air pump.
2. The air hose.
3. The rubber suit.
4. The breastplate.
5. The helmet.
6. The weights.
7. The belt and knife.
8. The life line.
9. The crinoline.
10. The shoes.
11. The lamp.

The air pump.—Two kinds of air pumps are used at the torpedo station in the instruction of seamen; one known as the American and the other as the English pump.

The American pump (manufactured by A. J. Morse & Son, Boston) consists of three single-action cylinders, each capable of supplying about 40 cubic inches of air per revolution.

The pistons have holes through their axes in which leather-faced supply valves are fitted and kept in place by spiral springs.

A similar valve for the outlet of air is placed at the bottom of each cylinder, and on the down stroke of each piston is opened and connects the cylinder with the supply pipe running under all three. Motion is communicated to the piston by means of connecting rods joining them to the crank shaft.

The three cranks are set at angles of 120° with each other. At one extremity of the shaft is a flywheel, while the other extremity is fitted to receive a crank handle. The tops of the piston rods pass through guides on the pump frame. The cylinders are surrounded by a tank which is kept full of water to keep the air cool. A pump, worked by an eccentric on the crank shaft, keeps the flow of water in the tank continuous.

The air pump is set in a strong wooden case, and low down on the sides of the case are the ends of the supply pipe to which the air hose is connected. If two divers are to work at the same time, the air hose can be connected to each end of the supply pipe, but if one diver is to go down at a time, the second air nozzle is closed by a plug which is screwed into it. The pump has no depth or pressure gauge and is always worked in its case.

The English pump (manufactured by Siebe & Gorman, London) consists of two double-action cylinders, each capable of supplying about 135 cubic inches of air per revolution.

The pistons are solid, and motion is communicated to them by an arrangement similar to that in the American pump. On the top cap of each cylinder are two valves, one the inlet valve and the other the outlet valve for air; on the foundation plate on which the cylinders are placed are also two valves of similar shape and for the same purpose, viz, outlet and inlet valves. The top and bottom outlet valves are connected by a passage at the side of the cylinder leading to the nozzle, to which the air hose leading to the diver is attached by means of a nut and joint. This pump can supply air to two divers working independently at different levels, each diver being in direct connection with one of the cylinders. A depth and pressure gauge shows the depth of water corresponding to the pressure of the air the diver is receiving, and serves as a guide to the men at the pump. The pump is secured in a strong wooden case and has one flywheel and two winch handles; these handles, and those of the American pump, can be taken off and protecting nipples screwed on during transportation. A water tank surrounds the cylinders to cool the air; it is filled by hand and emptied by a "draw-off" pipe, there being no pump attached. On the front of the case is a valve handle working in one of the outlet pipes.

Two brass plates are also fitted at the same place, one reading "one diver deep water" and the other "two divers." By turning the valve handle to the first both cylinders deliver air to one nozzle, and by turning it to the second the cylinders supply air independently, one to each nozzle.

The air hose.—The American air hose consists of a vulcanized-rubber tube surrounded by a 5-ply canvas covering.

The English air hose consists of a vulcanized-rubber tube with a galvanized-iron wire embedded.

The idea in both is to preserve the shape of the hose so that the diver's supply of air may not be cut off in case the hose is stepped upon or otherwise subjected to pressure that might deform it.

Both kinds are made in lengths of 50 feet, and the internal diameter is one-half inch. The metal union joints being used to fit the hose together.

The rubber suit.—The suit is made of solid sheet india rubber, covered on both sides with tanned twill; it has a double collar, the inner end to pull around the neck, the outer one of vulcanized india-rubber to go over the breastplate and form a water-tight joint. The cuffs are also of vulcanized india-rubber and fit tightly around the wrists, making, when secured by "snappers," a water-tight joint, leaving the hands free.

The breastplate.—The breastplate is made of tinned copper. The outer edge is of brass and has 12 screws securely fitted to it at intervals and projecting upward. These screws pass through corresponding holes in the outer collar of the dress, the four pieces of the breastplate band being secured to them by thumbscrew or wing nuts. The neck of the breastplate is fitted with a segmental screw similar to that on the helmet. There are two studs on the front of the breastplate to which the front and back weights are attached.

The helmet.—The helmet, of tinned copper, has a segmental screw at the neck corresponding to that of the breastplate, which enables the helmet to be removed from the breastplate by one-eighth of a turn. The American helmet has four strong plate glasses in brass frames protected by guards; the English helmet having three. In either the front glass can be unscrewed to enable the diver to give or receive order without removing any other portion of the dress.

An out valve is provided at the back of the helmet, a spring, which can be regulated for different depths, preventing the air from flowing out too fast, and the pressure of the water seating the valve thus preventing any entrance of the water.

An elbow is securely fitted to the helmet in which is placed an inlet valve, the air hose being screwed on to the elbow by a screw coupling. The inlet valve is so fitted that the air can enter but can not escape, so that in case of a leak in the air hose enough air is kept in the suit to allow the diver to be hauled to the surface before being suffocated.

The air, after entering the valve, is conducted by pipes in the top of the helmet to the diver's face, so that he inhales fresh air and his breath does not condense on the face-plate. There is a brass stud on each side of the helmet, the life line being made fast to the one on the right and the air hose to that on the left side. A foul-air valve is fitted on the left side of the helmet near the front.

The weights.—The front and back weights are of lead, heart-shaped, and weigh about 40 pounds each. Sometimes, instead of using the ordinary back weights, a leather belt, made with pockets into which lead weights fit, is used. These weights can be removed when necessary, thus making it an adjustable belt for both large and small men.

The life line.—The life line is used to haul up or lower the diver; and is also a method of communication by signals with the surface. It is cable-lain to prevent kinking and is about 2 inches in circumference. It should be about 30 fathoms long and marked at every fathom for convenience.

The belt and knife.—A leather belt goes around the waist and serves as a support. It carries a knife for use when working on wrecks, etc. The blade enters the sheath and the lower part of the sheath to keep the knife from dropping out.

The shoes.—The shoes are of stout leather with either lead or iron soles and are secured over the instep by two straps and buckles. Each shoe weighs about 20 pounds.

The crinoline.—The crinoline is a sort of wicker ring covered with cloth, and goes around the waist line inside the suit to support the body in opposing the pressure of water when diving at considerable depths. The diver himself is the best judge as to whether he needs it or not. It is not generally used in the United States.

The lamp.—The lamp is an incandescent 150-candlepower lamp of commercial construction. Its voltage depends upon that of the dynamo from which the current is derived.

The handles consist of brass tubes, the upper end of which carries the incandescent lamp and with its accompanying parts provides for the secure attachment of the outer ends of the leading wires in such a manner that short circuiting, whether by water or metallic contacts, is avoided. Inside the upper end of the brass tube is secured by three screws, an ebonite sleeve with the socket for the incandescent lamp secured to it by two screws. Inside the lower end of the brass tube is soldered, water-tight, a brass stuffing box carrying a seat for a rubber packing and fitted with a screw-thread for a water cap, thus providing a water-tight entrance for the leading wire through the water can and rubber packing into the handle, and to the binding screws of the lamp socket.

A rubber tube forms the junction of the lamp with the upper end of the brass tube. After the rubber tube has been slipped over the brass tube the lamp is shipped in its socket and the rubber tube is slipped up until it covers the globe of the lamp to a height of about 1 inch above the brass collar of the lamp and is held in place by a temporary seizing. The rubber tube is then turned back from the globe, a coat of thick shellac is applied to the glass surface exposed, and to the collar of the lamp, and while the shellac is still wet, the rubber tube is replaced. When the shellac is dry the rubber tube is secured in place by flat seizings of stout flax twine, a narrow seizing being passed around the rubber tube and the neck of the lamp globe, and a broad seizing around the rubber tube and the brass tube for the entire length of the latter.

The guard frame, to protect the lamp from breakage and help to sink it, is made of stout brass wire. The frame is made in two parts, upper and lower, which, when assembled, are secured together at the equator of the frame by four machine screws. The upper half of the frame carries a ring by which the lamp may be hung up when desired.

The lower half terminates in a collar, slit in three parts which, inclosing the handle, is held firmly in place by a stout seizing or marline passed around it.

The shield is used to protect the eyes of the diver from the glare of the lamp. It is made of copper in the shape of a dish and is fitted to the outside of the guard frame. The inside face of the shield is silvered and polished to serve as a reflector. When all-around illumination is desired the shield is taken off.

The leading wire is of the double conductor type, 100 feet, being furnished with each lamp. The pattern is the same as that used in spar torpedo work.

The connector is a plug designed to fit the sockets of the particular system of lamps carried by the ship to which the diver's lamps is issued. The inner ends of the lamp leading wires being secured to two binding posts in the connector, connection between the diver's lamp and the dynamo can readily be made by shipping the connector in any standing lamp socket conveniently placed.

Each diver's lamp complete is firmly secured in a lock box of special design, in the corners of which are pockets for the connectors. A copy of instructions is pasted on the inside of the lid. Each box is marked on top "Diver's lamp" and is packed in a rough box for transportation.

Care must be exercised that the current is not turned on until the lamp is entirely submerged, and that it is turned off before the lamp is removed from the water. Neglect to observe this precaution will result in breaking the globe.

Keep the leading wire free from kinks and subject to as little strain as possible. To prevent the leading wire of the lamp from being torn out of the socket by sudden pulls, seize it to the ring on top of the cage. After using, carefully clean and dry the apparatus.

CHAPTER II.

ACCIDENTS THAT MAY HAPPEN.

The air supply may be cut off by the pump, the safety valve may be out of order, or the air hose may break, above or under the water. The supply of air in the suit will last only four or five minutes. If the diver can not come up alone, pull him up by the life line; if this is broken or foul, use the air hose. Rapidity of action is imperative.

By throwing himself on his back the diver may cause the air to go into the legs and upper part of the suit, and by this means may help himself in coming to the surface. If the knife is handy, he can cut off the front weight; this will throw him on his back and effect the same object.

RULES FOR RESUSCITATION.

General rules.—As soon as the body comes or is brought to the surface it should be lifted head first into the boat or on deck. The front glass of the helmet should be opened and the helmet and weights taken off; if necessary, the suit should be cut off; at the same time send for a doctor.

Drowning.—Do not stand the diver on his head. If weather permits, lay him face downward in the open air with a pad of clothes under his stomach. Clear his mouth and palate and loosen all tight clothing, especially around the neck and head, and excite the nostrils with snuff or ammonia or tickle the palate with a feather. Chafe and rub the breast and face, and sprinkle both with cold water. If he shows no sign of breathing, lay him on his stomach again, with a pad of clothes under his breast and one arm across his face, at the same time firmly pressing a hand between his shoulder blades. Carefully turn the body on its side or a little farther and then rapidly on his stomach again about 15 times a minute, at the same time supporting the head. Reverse and turn on the other side alternately. While this is being done dry and rub hands and feet and remove wet clothing.

If no indication of breathing appears after several minutes, turn him on his back, laying a pad under his head and neck so that the chest is high. Pull his tongue forward and keep it there, tying a string around the tongue and chin if necessary. Get behind his head; grasp both arms just above the elbows, and steadily but gently bring them extended above his head, holding them there about 2 seconds; then shove them down alongside his body again for 2 seconds, and keep this up about 10 times a minute.

As soon as he begins to breathe lay him on his back, chafe his limbs and body to induce warmth and circulation of the blood. Place hot-water bottles around the lower part of his body and cover him up warmly. As soon as he can swallow give him from time to time a little lukewarm water with wine or brandy or coffee or tea.

The effort must continue as long as the body is presumed to contain life and cease only when the pallor and rigor of death has set in.

Suffocation.—Lay the diver on his back with his head raised, clean the mouth and palate, and thoroughly sprinkle the head and face with cold water. Give cold douche and proceed as in case of drowning.

If a doctor or apothecary is present, let him bleed the patient. As long as there are no pronounced indications of death the efforts at resuscitation must be continued.

CHAPTER III.

SIGNALS.

Different methods of communication between diver and the surface are now in use, such as the telephone, acoustic tube, and the slate. These have all been tried with more or less success, but are not regarded with much favor by practical divers.

A short description of a diver's telephone is, however, given that those using this book may have a general idea of its construction. The receiver is fixed in the helmet, is placed on the diver's head, and the receiver presses against his ear. The transmitter is so arranged that its position is in front of the diver's mouth. A special connection prevents the cable from being broken off at the point at which it enters the helmet.

The telephone is worked by a battery of six dry cells, which are contained in a leather case, which, by means of a strap, can be carried about by the attendant. This strap passes over the shoulder and the cells in the box are suspended by it.

In actual trials with this instrument it was noticed that no distinct sound could be obtained with this number of cells, the best results being obtained by the use of two cells in series.

The attendant's telephone was shaped like a handle, one end being used for a receiver and transmitter, the handle serving to carry the telephone about and the other end consisting of a thin diaphragm of rubber, under which was placed some finely divided graphite. This was not compressed into the form of a button, but was filled loosely into the case. If the attendant could not hear distinctly, by pressing the graphite with greater or less force he could hear properly, as he was enabled to change the resistance of the circuit. The current passes through a choke coil (a coil of copper wire wound on an iron core), and connections were so arranged that the attendant could converse with one or two divers.

One hundred and fifty feet of cable were used with the outfit, and the different wires were made into a single cable.

The life line and the air hose provided with the apparatus are means generally used in the service for making signals and are found quite sufficient for all requirements.

The following is the code adopted at the torpedo station in the instruction of seamen qualifying as seamen gunners. The important point to observe is that the diver and tender have a thorough understanding of the signals to be used.

ON LIFE LINE.

Pulls.	By diver.	By tender.
One........	Am "all right"	Are you "all right"?
Two.......	Ease me down.................	I will ease you down.
Three......	Pull me up.....................	Come up; or, I will pull you up.

ON AIR HOSE.

Pulls.	By diver.	By tender.
One........	More air.........................	Answer by 1 pull on life line (I will comply).
Two.......	Less air..........................	Answer by 2 pulls on life line (I will comply).

Two pulls of the life line and two on the air hose, in rapid succession, indicates that the diver is foul and can not free himself. On receiving this signal no attempt should be made to haul him up, but his signal should be answered and another diver sent down to release him.

Never arrange a code of signals for carrying on work that involves any of the established signals on life line, as it is a dangerous experiment and may lead to serious misunderstanding.

THE PERSON IN CHARGE.

The person in charge must thoroughly understand diving and the use of the apparatus. He must also understand the rules for resuscitation and the care of persons injured in diving. He will see that a full complement is present at the work, or exercise, and will have full charge in all things.

He will assure himself that the diver understands the different parts of the apparatus and what to do. Also that all parts of the apparatus are correctly and thoroughly adjusted.

He will see that the pump is worked regularly, closely observing the gauge to see if air is being delivered properly. He will see, also, that the tender leaves just slack enough on life line and air hose for the diver to work by.

He will cause the diver to come up if, when anchored in a current, bow and stern, the position of the diving launch is to be changed or any alteration occurs on the surface which may interfere with or imperil the diver.

If engaged in clearing mooring cables or lines, no hauling or veering should be done until the diver comes up. As soon as one man comes up, if another is to go down, coil down the air hose and life line and examine the pump and all valves and joints afresh while the second man is being dressed.

Make it a rule to keep the gear in the diving boat neatly arranged and place all articles not in use well out of the way. No talking or laughing is to be allowed after the diver's faceplate is put on or while he is under water.

THE DIVER.

Coolness and courage are the necessary qualifications for good divers. A diver should not go down for at least one and one-half hours after eating a hearty meal or for two hours after drinking spiritous liquors. He should empty his bladder and, if the diving is to continue for any length of time, relieve his bowels before going down, as the increased pressure will not only cause great inconvenience, but probably disagreeable consequences if this precaution be neglected.

He will not go down or come up on any anchor, cable, line, or rope secured to the bottom. When working on the bottom, a weight with a line attached, called "circulating line," is used as a guide in moving about. If under the bottom of a ship, a Jacob's ladder, coming underneath and up each side, is convenient.

Fouling of the life line or air hose might occur when working on a wreck and if the diver can keep cool he may be able to follow up his line or air hose and free himself.

THE DIVER'S TENDER AND ASSISTANT.

A diving crew consists, in addition to the diver, of the following men:

1 diver's tender.
1 assistant to diver's tender.
1 man to observe pressure gauge.
2 men to man the pump.

Two men should be added to this complement as reliefs to the pump men when carrying on operations in deep water or where the work is arduous or continuous.

THE TENDER.

The tender is the responsible person and must be vigilant at all times. Occasionally he will give one pull on the life line, and the diver should return the signal by one pull, signifying "all right."

If the signal is not returned, the diver should be hauled up, but if he wishes to work without interruption he gives one pull independently for "all right; let me alone."

If the tender feels any irregular jerks, such as would be occasioned by the diver falling into a hole, he should signal to know if the diver is "all right," and if no reply is received should haul him up immediately. If while being hauled up the diver gives one pull, it signifies "all right, lower away."

If the tender wishes the diver to come to the surface, he gives three sharp pulls on the line, to which the diver answers (three pulls) if he is ready to come up; otherwise (one pull) if he wishes to remain longer below.

He will see that the diver does not descend or ascend too quickly, controlling his motions by signal and the life line. He will never allow a man to go down in more than 20 feet of water without a "descending line" made fast to the diving launch.

He will carefully observe the air bubbles as they come to the surface. If they rise at regular intervals of three or four seconds, the diver is all right and breathing regularly. If the bubbles rise continuously without any interval, the diver is nervous. In a current the bubbles will appear a distance beyond and may not be seen. In this case use signal (one pull) very frequently.

He will always make fast the bitter end of the life line in the diving launch. His assistant will aid him in keeping lines clear and coil down and may attend either the hose or life line when so directed and will always be ready to assist in pulling the diver to the surface in case of emergency.

THE PUMP MAN.

Under no circumstances must the men at the pump allow their attention to be diverted from their work while the faceplate is on and the diver down. The pump must be worked steadily and uniformly, the speed designated by the man watching the gauge.

CHAPTER IV.

PREPARATION.

General remarks.—As a general rule diving operations can be carried on better from a boat or stage than directly from a vessel. If it should be necessary to send a diver under a vessel near the gangway, the platform of the gangway could be utilized as a place for the pump and attendants, but the boat or launch is used by most experienced divers.

Always hoist a red flag in the bow of the diving launch as a warning for other boats to keep clear of you. Never carry on diving operations in foggy weather unless it is absolutely necessary to do so. In that case, sound the fog signal very frequently.

Details of preparation.—1. In working in a tideway moor the launch head and stern and have a small boat alongside ready in case of accident. An iron ladder should be provided, with stays to bear against the sides of the launch from which the diving is carried on. If working in deep water, a Jacob's ladder, weighted on the end, should be attached to the iron ladder if the diver so wishes.

2. Lash the pump securely to the launch, placing it so that it may be about 6 feet from the head of the ladder and facing it. Examine all the working parts very carefully and oil them. None but the best olive oil should be used, as the smell of other oils is apt to make the diver sick, especially if he is a beginner.

3. Examine the inlet and escape valve in the helmet to see if they seat properly; even a grain of sand may cause a valve to leak by preventing its seating properly. Therefore be very careful in this examination. See that the foul-air valve works properly; if the diver is working on his back in the mud, the escape valve may be closed and then the foul-air valve becomes of the greatest importance.

4. If the suit has been in store for any length of time, clean off the verdigris, take the valves apart, and tallow them slightly. Examine all couplings and test the air hose by placing the hand over the end of it, working the pump at the same time. Listen for leaks about the pump at this time. A second method of testing the air hose for leaks is to hold the end in the hand and pay the bight overboard gradually; any leak and its position will be shown by the presence of bubbles as that particular part goes in the water.

5. Connect the pump for the cooling tank (American pump) and ship the crank on the main shaft. When satisfied that the pump is ready, proceed to the next step.

6. The diver dresses as follows:

(*a*) He first puts on a suit of heavy woolen underclothes, then the shoulder pad; sometimes a soft woolen cap is worn to prevent colds in the head from the current of air from the pump. If diving in shallow water, the crinoline may be left off; otherwise it goes on at this time.

(*b*) He then gets into the suit through the neck part, lifting it up as soon as the arms are in the sleeves, the cuffs being opened by an assistant with a pair of cuff expanders. Pull the inside collar well up. If the diver is to wear gloves, the rings must be put on; otherwise put on the "snappers" over the edges of the cuffs. In cold weather warm the suit before attempting to put it on.

(*c*) The shoes are next put on and buckled and the breastplate placed on the shoulders, the diver sitting down while it is done.

(*d*) The outside collar is then drawn very carefully up over the breastplate screws so as not to tear through the holes in it. Now put on the four parts of the breastplate band and screw them up securely with wing nuts, the center screw of each part of the band being set up first. Then put on the chafing pants or overalls.

(*e*) Put on the belt and secure the life line around the waist. The diver is now helped to the diving ladder, and as soon as he is on it the life line must be secured to a cleat or bolt so that there may be no danger of his slipping off.

(*f*) The front and back weights are then put on and secured by a line attached to them and made fast around the body.

(*g*) Start the pump to expel any sediment that may have accumulated in the air hose, as well as to drive out the hot air. The helmet and its glasses having been cleaned, screw the air hose to it. Put on the helmet, leaving off the faceplate. One-eighth of a turn will firmly secure it to the collar of the breastplate. If the helmet has the safety-pin arrangement, put in the pin to keep it from unscrewing.

The air hose passes from the back of the helmet down the left arm and is secured to a lug on the left side of the helmet in front. The life line passes around the body with a loop, and is then stopped to the lug on the right side of the helmet.

7. The pump is now started and the face plate screwed on, the diver breathes regularly for a few minutes, when the pump is stopped and the face plate unscrewed. The diver is then asked if everything works satisfactorily; any defects must be immediately remedied.

8. If everything works right, the order "pump" is given, and the face plate screwed on. The diver is then given a pat on the helmet as a signal that all is ready and that he is to descend.

Operation.—The pump should be worked steadily and the tank surrounding the cylinder kept full of water to cool the air; in warm weather ice may be used in the tank with the water. The diver's depth will be determined by the amount of life line out; with the English pump the depth and pressure gauge will show this.

Generally the pump should be worked so as to give above 5 pounds per square inch more than the pressure required for the depth. At any hard or fatiguing work the diver will need more air than when at light work or resting.

The diver should descend slowly, about 1 fathom a minute, stopping for a moment after his head is under water to satisfy himself that he is all right. If he feels oppressed or experiences a humming noise in his ears, he should rise a few feet and swallow his saliva a few times.

He must not continue to descend unless he feels comfortable. If the oppressive singing in the ears or the headache continues, he must return slowly to the surface.

The nervousness occasioned by the first attempt at diving increases the pulsations and causes a peculiar gasping for breath; this happens in some cases to be so strong that it would be advisable while in that condition not to allow a man to descend. An explanation of the apparatus and the example of others will soon banish the nervous fear, and by descending slowly and rising a few feet when feeling uncomfortable the body will accustom itself to the change of pressure and the disagreeable feeling will wear off.

The diver should habitually walk backward; if he strikes an obstacle he should turn around and feel, as there is danger of the glasses in the helmet being broken by spikes or other objects, especially if working on a wreck.

On arriving at the bottom the diver will give one pull on the life line to signify that he is "all right." While under water the diver requires a tender to hold his life line and air hose and an assistant to keep them clear. Both the hose and the life line should be just taut and clear of the gunwale so that at any moment the diver may be felt.

On going down the diver takes with him a ladder line if a weighted Jacob's ladder is used; this he attaches to the foot of the ladder. As he leaves the ladder he pays out on the line, but keeps the bitter end fast to his wrist by a loop, so that at any time he can find his way back if he wishes to return. He must return to the ladder by the way he left it, otherwise he may foul his air hose or life line.

If two divers are down, they must work together and understand each other, being careful not to cross each other's path for fear of fouling the lines or air hose.

The diver must not lose courage or become frightened; if he does, or if he feels the want of air, or if his nose bleeds, or if he feels sick, he should immediately give the signal for coming up, but should not come up too fast—about 1 foot a minute, if possible.

In case the air hose gets foul, it may be noticed when, after repeated signaling (one pull on the air hose, "more air"), sufficient air does not come. After trying to clear it, as a last resort, in moderately deep water, signal (three pulls on life line), throw off breast lead, cut the air hose, holding the end tightly, and come up. This should only be attempted when there is no second suit available with which to go to the assistance of the diver.

If sunk deeply in soft ooze or mud, signal "more air," close foul-air valve, and close escape valve (if it can be reached) with the finger. This will inflate the suit more and probably free the diver.

CHAPTER V.

METHOD OF INSTRUCTION.

None but experienced and reliable persons thoroughly understanding diving should be intrusted with the instruction, which should be as follows:

1. The pupil will first be instructed in the general construction of the apparatus and shown how to disassemble and assemble it.

2. Full instruction in signaling will be given, combined with practical work in transmitting and receiving signals by life line and air hose.

3. The suit and helmet will be put on and the pupil will practice breathing for a while, the pump being worked regularly. He must accustom himself to the unnatural

position of being shut up in a suit and endeavor to overcome any tendency to nervousness.

4. The pupil, fully clad, will enter the water. He will remain near the surface and will endeavor to accustom himself to the different sensations and pressures. If he feels any distress he should come up.

5. Practice is next had in sinking to the bottom and in ascending. Sometimes heavy sweating and a disagreeable ringing in the ears occurs. This is caused by a greater pressure at a greater depth, and will gradually disappear with practice. If the pressure in the ears pains the pupil, he must stop and swallow his saliva. If this does not relieve him, he must, if the distress occurs during descent, ascend a little until accustomed to the pressure, and then continue the descent; or, if the trouble occurs while ascending, he must descend a short distance until relieved.

6. Practice in working under water; the bodily efforts give the lungs more work, thus making the labor more exhaustive. First do easy work and then practice moving heavy weights and digging. It must be understood that bending forward increases the difficulty in breathing, and that sitting or kneeling is the best position for heavy work.

7. The instruction of the pupil will be completed in all the details of the apparatus and its action with practical exercises in disassembling and assembling the parts. He will be required to possess a thorough knowledge of the rules and their application, and of what is to be done in the various contingencies that may arise.

Chapter VI.

CARE AND PRESERVATION OF APPARATUS.

The apparatus must be overhauled weekly and after every time it is used. It is to be always kept in repair. After being used the suit must be washed off with clean, fresh water, and, in case salt water has entered it, that part must also be washed. It must then be hung up in a cool, dry place, but not in the sun or where it is too hot. Each time it is laid away it must be folded in a different manner so that no creases will form.

A convenient stretch upon which to dry the dress, heels up, is made of two cross batten to go up the legs, and a third loose through the arms.

The cylinders of the pump must be thoroughly cleaned, polished, and oiled after being used. After detaching the air hose from the helmet, air must be pumped through it, and the threads on the couplings must, after being cleaned, be protected by pieces of linen.

The shoes must be washed off in clean, fresh water, dried very slowly, and then greased.

The helmet must be cleaned, dried, and polished.

Overalls and belt must be cleaned and slowly dried.

Underclothes and overalls must be frequently aired and beaten out to preserve them from moths and mildew.

If the suit is torn or damaged it may be repaired with the prepared cloth and rubber cement in the supply box.

In repairing a diving dress first wash the part requiring repairs with clean, fresh water and let it dry thoroughly. Put on a coat of the cement and rub it in evenly, allowing it to remain about two hours before the second coat is applied. The second coat is rubbed in evenly, similarly to the first, and allowed to remain about thirty minutes before putting on the third coat. Let the third coat dry so that it just fails to stick to the fingers. The patch of repairing cloth should be given an even coat of cement about 10 minutes before being applied. Very little pressure is required, as the texture of the dress and the repairing cloth make them adhere easily.

CHAPTER VII.

DIVING OUTFIT.

A complete diving outfit consists of—

1 air pump.
3 pieces of air hose (150 feet) with couplings.
1 helmet.
1 breastplate.
2 diving dresses.
1 set of weights.
1 pair of diving shoes.
1 pair of wrist expanders.
2 pairs of ring mittens.
1 pair ring and clamps.
12 feet of snap tubing.
1 shoulder pad.
1 pair of overalls.
1 life line.
2 wrenches for setting up nuts on breastplate.
1 dozen extra bolts and screws for helmet.
1 can of rubber cement.
1 yard of repair cloth.
1 pair of extra couplings.
1 safety check valve.
1 cutting punch.
2 pairs woolen stockings and 2 pairs woolen mitts.
2 suits woolen underclothes.
1 basket for helmet, hose, and dresses.

PRESSURE AT DIFFERENT DEPTHS.

The following table represents the pressure in pounds per square inch, to the nearest half pound, at a given depth of water:

	Pounds.
20 feet	9
30 feet	13½
40 feet	18
50 feet	22½
60 feet	27
70 feet	31½
80 feet	36
90 feet	40½
100 feet	45
110 feet	49½
120 feet	54
130 feet	58½
140 feet	63
150 feet	67½
160 feet	72
170 feet	76½
180 feet	81
190 feet	85½
200 feet	90

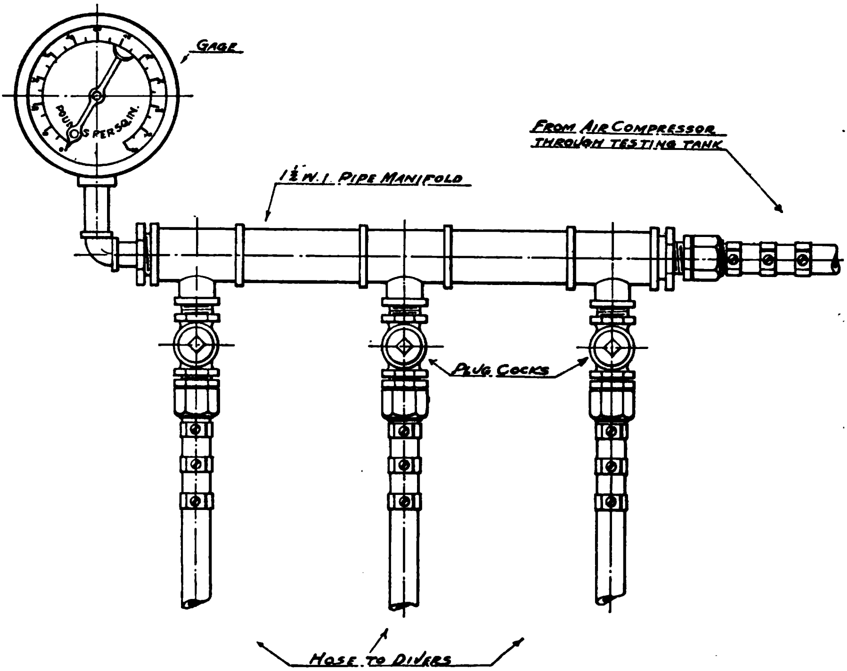
As a rule diving should not be carried on much below 20 fathoms, although experienced divers have gone as deep as 34 fathoms.

[Inclosure (X).]

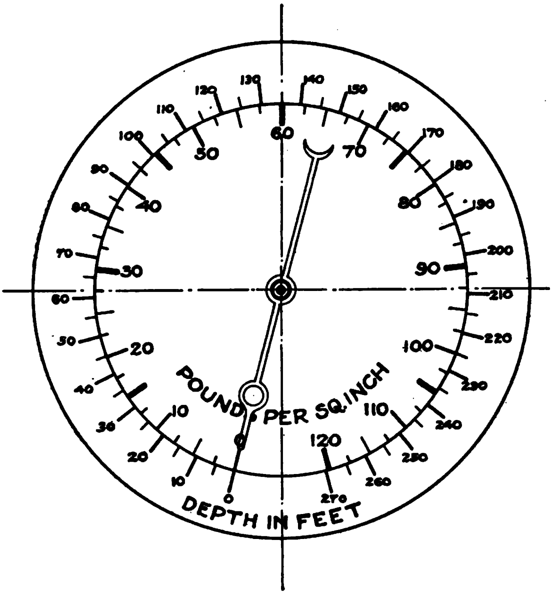
DESCRIPTION OF DIVING MANIFOLD.

The manifold is for use in connecting two or more pumps together and for connecting the air-supply hose of one or more divers to the source of air supply.

For method of application see paragraph (200) of the report (67–T).



Manifold for diving apparatus.



POUNDS PER SQ. IN.	DEPTH IN FEET
4.45	10
8.90	20
13.36	30
17.75	40
22.19	50
26.72	60
31.16	70
35.57	80
40.01	90
44.50	100
48.93	110
53.36	120
57.91	130
62.33	140
66.73	150
71.14	160
75.60	170
80.11	180
84.52	190
89.08	200
93.49	210
97.90	220
102.31	230
106.67	240
111.28	250
115.69	260
120.24	270

Pressure and depth gage for diving apparatus.

[Inclosure (Y).]

COPIES OF CORRESPONDENCE RELATIVE TO DIVING IN THE NAVY.

EXPERIMENTAL DIVING STATION, UNITED STATES NAVY,
783 Atlantic Avenue, Brooklyn, N. Y.

From: Gunner G. D. Stillson, United States Navy.
Subject: Submarine armor, diving apparatus, appliances, diving operations, etc.

1. There are being conducted at this station an extensive series of tests and experiments to correct the defects and imperfections existing in various types of diving apparatus, and to demonstrate a new and improved method of diving, by which the efficiency of diving operations is much increased.

2. Similar tests and experiments have been accomplished in various European countries, and with the information obtained from abroad and particularly from the result of investigation at this station, many defects, some serious, have been found to exist in all types of diving apparatus and in the manner of its employment.

3. It is but reasonable to suppose that American apparatus and American divers are the equal, if not superior, to any that can be produced elsewhere, and with the end in view of assisting divers, and to make the result of these tests as complete and authentic as possible, your cooperation and assistance is requested.

4. It is desired that you forward to me at the above address such information that is either interesting or instructive, together with any suggestions you would care to make in regard to improvements in methods of diving, and in construction of diving apparatus.

5. As a guide to what is desired the following list is arranged in the order of its importance:

(*a*) Suggestions for improvements in construction of diving apparatus.

(*b*) Suggestions for improvements in method of conducting diving operations.

(*c*) Criticisms of present types of diving apparatus, and various methods of diving.

(*d*) Description of important diving operations, including that of apparatus, divers, method of diving, times of descent, remaining under water, and ascent, effects on divers, depths reached, and general remarks, etc.

(*e*) Detailed description of all accidents to men or apparatus.

(*f*) What is considered the maximum depth at which divers can perform useful work under water?

(*g*) How may the apparatus be adapted for use at greater depths?

(*h*) What precautions should be observed to protect divers from the dangers to which the nature of their work subjects them?

(*i*) Which do you consider the most efficient form or type of diving apparatus?

(*j*) How would you organize a school of instruction for divers? How would you proceed with the instructions of candidates for the course in diving?

(*k*) What are your suggestions in regard to pay of divers?

(*l*) What constitutes a day's diving work under various conditions of climate, location of operations, state of the weather, depth of submergence, nature of work, etc.?

(*m*) Original remarks, suggestions, etc., are especially solicited.

6. Any information received from you, if used, will be classified and incorporated in a final report and credit will be given you for same.

7. Owing to the probable great length of the final report, a copy of same at this time can not be promised, but if possible a summary of the most interesting points will be forwarded to those from whom information and assistance is received.

UNITED STATES NAVY YARD,
Boston, Mass., March 27, 1914.

From: Gunner Arthur D. Freshman, United States Navy.
To: Gunner G. D. Stillson, United States Navy.
Subject: Submarine armor, diving apparatus, appliances, diving operations, etc.

Referring to your letter of March 14, I have the following comments, suggestions, and recommendations to make on the subject of your request.

2. It will be acknowledged that the principal item of any diving apparatus is the means by which fresh air is supplied to the diver. This brings up the consideration of diving pumps now in use in the naval service. After various experiences in charge of diving operations, certain tests witnessed, and a great deal of study of this phase of the subject in connection with the investigation and experiments conducted by yourself on board the *New Jersey*, I am of the opinion that the present Navy diving pump is not suitable for diving operations at depths exceeding 100 feet, and only at this depth when certain minor changes in design have been made.

3. With the valves, leathers, washers, pistons, etc., of the pump placed in efficient condition and kept so, it is believed that this type of pump has sufficient capacity to offset small deviations from the theoretical curve at a pressure equivalent to 100 feet of sea water.

4. With a view to improving the pumps now in service the following suggestions are made:

(1) Fit a portable section in front of wooden casing of pump large enough to make the exterior parts of pump accessible for inspection and adjustment.

(2) Make the present 3-way cock with a longer taper and hexagonal section at its upper end, with a corresponding socket on the lower end of shifting lever. By removing the lever the cock could be adjusted, using a wrench on the hexagonal section.

(3) Provide extension handles on flywheels for use when diving operations are carried on at depths requiring more power to supply air than can be furnished by shifts of two men, these handles or cranks to be of the same type as portable sets now installed in ships for hand ammunition hoists. Provision for the securing of the bearing brackets of these handles can be made part of the standard fittings of boats likely to be used for diving purposes. If desirable, bearings need be provided only with the diving outfit, and provision for the reception of the fittings could be made in the boats. If extension handles of this type are not considered desirable, then longer handles of the type now in use should be furnished.

(4) Make the present flywheel heavier by the addition of weights, similar to the driving wheels of a locomotive.

(5) For supplying air to divers at depths exceeding 100 feet, I am of the opinion that a power driven pump is necessary.

It is believed that a light engine, using kerosene, would give the best results. I would not advocate gasoline as the fuel, because of the possibility of gas fumes getting into the air supply. Where any explosive engine is used, I would suggest a filtering arrangement between the pump outlet and the hose. This pump should also be supplied with a reservoir or tank, with a capacity of not less than 2 cubic feet.

Specifications for diving pumps.—Regarding specifications for diving pumps, it would seem that they should state just what is meant by an efficient pump. In other words, specify just what this pump should do with the application of a given amount of power. It is also recommended that specifications include spare leathers for pistons (and, if desirable, molds for same).

Telephones.—After several attempts to communicate with divers under water by means of the telephone outfit now supplied with diving apparatus, I believe that better results could be obtained by using receivers similar to fire-control head sets instead of the present helmet receiver. This idea, I think, has been taken up by Andrew J. Morse & Son. I have found that it is possible to coach certain men to use the present type of telephone with fair success, but the noise of the pump bothers a majority of divers to such an extent that communication is almost impossible. With a power pump this difficulty would, of course, increase, In this connection experiments with loud-talking telephones are suggested.

Another desirable change which I suggest is fitting arrangements for jacking over terminal, so that it could be made possible when two divers are under water to connect their phones in such a way that communication between them would be established. I should also provide a "listening in set" for the person in charge of diving operations.

Signal or life lines.—A strong cable-laid signal line, having the telephone cable laid up inside is recommended, this line to be of not greater diameter than ¾ inch. Almost any small line is suitable for use as a signal line, but should it become necessary to forcibly extricate a diver from mud or other obstruction the ordinary signal line used would not answer. The line must, of course, be of small diameter to lessen resistance to tides and the consequent drag on the diver. By making up the telephone cable inside of the signal line strength would be added and the amount of gear to be handled made less.

Diving dresses.—For future specifications dresses with laced legs should be specified to the exclusion of the present type. It is well known that dresses with laced legs would overcome to a great extent one of the dangerous possibilities of diving operations—that of being "blown up".

A properly designed ladder for diving operations is one of the items of diving equipment not furnished, and, in my opinion, urgently needed. On board ship this article is generally of a makeshift or temporary nature, the use of which leads to delay and possible injury to the diver or apparatus. Especially is this true with much motion on the diving launch. A standard ladder, suitable for all square stern boats, is suggested, along the following lines:

Iron ladder, inclined, flat treads, iron hand rail, with 24-inch stanchions; ladder to secure inside gunwale of boat with stay rods about 18 inches long from sides, to hook into eye on stern of boat; bottom of ladder to be rounded and fitted with puddings.

Diving operations, inspections, and tests.—I would suggest that before diving operations are started the diver be examined by the medical officer, with special reference to the physiology of diving; this examination to be a matter of record, and a report made to the proper officer before any man is allowed to dive. The diving operations should be a matter of record, and to this end a journal or log should be kept, the form to be similar to other logs now furnished; the logs to be furnished by the bureau. Some of the columns suggested are:

Locality, depth, character of bottom, serial number of descent, name of diver, number of pump, weather, tide and sea, amount of sunlight, opaqueness of water to diver's vision, time of descent, time of ascent, nature of work, average revolutions of pump at working depth, special mention of unusual incidents; also whether the purpose of the operations was accomplished. This report to be signed by the officer in charge. In addition, after the completion of diving operations, a card similar to "Report of torpedo practice" should be forwarded; this card to include the principal columns of the log.

All parts of the diving apparatus to be thoroughly inspected and tested semiannually by a competent officer; this to include actual tests of pumps according to a prescribed formula pumping into a container of known capacity, etc.

All qualified divers who have not actually performed diving work within one month preceding the semiannual test should be given instruction in diving. Each diver should be given at least one hour's instructions in the various phases of diving operations. No pay should be given for diving work thus performed, and the results of the semiannual tests, inspection, and instructions to be covered by a report. It is considered important that men should dive at least once in seven months. The writer has in mind an incident in which he was in charge of diving and there were seven qualified divers available; of these but one man had been in a diving suit within a year. The others had not done any diving for various periods ranging from two to nine years. This further suggests the advisability of incorporating in a diver's enlistment record some records of his work as a diver, similar to a gunnery record. It is believed that if a man knows a record of his work is kept it would be a strong incentive to good work, and would undoubtedly be a great help in selecting men for important and remunerative work.

In discussing the pay and "day's work" for divers, so many features are presented that it is hard to suggest anything which seems fair and just under all conditions of diving. However, some points of this question can be covered as follows:

Pay for diving to be computed from time face plate is put on until it is finally removed; no account to be taken of rests, which should be at the discretion of the officer in charge. If less than one hour's work is performed, diver to be paid for one hour. When work is performed at depths greater than 20 fathoms, rate of pay to be double that of present rate, time to be computed as for lesser depths. Four hours is considered a day's work for men engaged in ordinary diving operations, such as searching, scraping propellers, examining bottom, zincs, valves, etc. Certain conditions of tide, depth, character of bottom, temperature of water, and character of work would be considered and shorten the time constituting a day's work. At depths exceeding 20 fathoms one descent in one day should be the limit, for the time consumed in decompressing a man should be considered. If a man feels no ill effects, and has been properly decompressed, and the necessity for a second descent is urgent, it should be undertaken only after a good rest, say one descent at 8 a. m., completed at 10 a. m.; second descent at 3 p. m., completed at 5 p. m.

Instruction.—Next to providing proper apparatus, I consider this to be most important, and closely allied with all phases of diving. The present practice is to make divers of all men in the seaman gunner's school who are physically qualified, regardless of other qualifications, such as temperament, degree of intelligence, and physical courage. It is believed that these characteristics should be considered before men are sent to the service as qualified divers, and that it is just as easy to turn out good divers as the other kind. All instruction should be made interesting. Below is given an outline of the course of instruction, divided into periods:

(1) Instruction to consist of elementary lectures on diving, its history, developments, and possibilities.

(2) Lectures and description of apparatus, giving whys and wherefores, as well as dry statements.

(3) Practical work in assembling and disassembling apparatus. Instructions in dressing and undressing. Use of Eustachian tubes, signals, and telephones. Adjustment and use of helmet relief valve. Instruction in Morse code and sound signals.

(4) Under-water work in tank large enough to accommodate four divers at one time. Vary condition of light, air supply, time under water, etc. Diver to perform light work. This would be the proper time to start plain talks on the physiology of diving, and its relation to the dangers of faulty air supply, oversaturation, and too rapid decompression. This feature to be completed just before deep diving is taken up.

(5) Work from tender in depths up to 50 feet. This to include instruction in the use of descending and circling lines, how to arrange apparatus in boat, getting diver on board, etc. Practical demonstrations to be given by an instructor descending in company with the pupil, using the telephone connected as suggested in an earlier

paragraph. Especially would this be valuable in the first descent of a man, as the use of the telephone could be carried out at all stages of the instruction, such as proper carriage, walking in mud, against tide, getting sense of direction, and recognizing objects. After men have been sent down alone at this depth and given a task to accomplish, any weeding out necessary would be evident.

(6) Assuming that all men under instruction will finish the course, take up practical work under water, slinging anchors in boats, working lines, covering areas, searching work with hand and power tools, digging, cleaning propellers and bottom, use of the slate, making sketches and measurements, recording observations, and recovering torpedoes. The use of explosives in destroying obstruction, piers, and possibilities of recovering sunken submarines should also be taken up. As far as possible all of the above should consist of actually performing the work outlined, and the instruction should be thorough and practical.

(7) The next period of instruction should take up power pumps and deep diving. Two hundred feet is set as the limit at which a diver can remain long enough to perform useful work. Under certain conditions, as with a decompression chamber, or where the work to be performed consisted of a simple operation requiring only a short time to complete, this limit might be considerably extended.

The instruction in deep diving would be simply an extension of the earlier work, and of course would include stage decompression, with special attention to times at each stage. It is believed that a rough guide could be established, using the computed tables, so that divers and others could memorize a formula for use in decompression work. The computed tables in a convenient form should be made a part of every diving outfit.

It is believed the limit of 200 feet should be reached in four descents, and in addition that each man should make at least one descent from the surface to 200 feet and perform some practical work, such as slinging heavy weights or unshackling chain. This period should have some time given to lectures on practical problems in deep diving, history of important diving operations, hydropneumatics, salving of submarines, etc. I would suggest that upon completion of the course that men be classified (*a*) men who have qualified at the maximum depth, and (*b*) men who qualify only at 60 feet, the higher qualification to be open to class (*b*) men after they are sent to general service, unless they are disqualified by reason of a permanent physical defect. Class (*a*) men to receive $5 per month extra compensation, inclusive of the $2 per month now paid to seamen gunners; class (*b*) men to be paid as at present.

Other features connected with the development of diving that might be mentioned are—

(1) The advisability of changing the bureau having cognizance of diving apparatus from Construction and Repair to Ordnance.

(2) The uniformly exhorbitant prices paid for this material, from the pump at $500 to the chafing mittens at $1.

(3) The preparation of a paper for distribution among medical officers of the Navy by the Bureau of Medicine and Surgery on the physiology of diving, effects of compressed air on human beings, and treatment in cases liable to arise because of the conditions divers are subject to.

(4) Possibilities of using diving apparatus connection with the air lock on submarines:

(*a*) For use in offensive operations, such as countermining, releasing, and planting mines; destroying important works, such as docks, bridges, obstructions, or vessels protected against other means of attack.

(*b*) Incidentally for escape from a disabled submarine.

I think feature (*a*) has been overlooked in the development of our submarines. The writer served three years in earlier types of submarines and has in mind an air lock or diving compartment which was part of the equipment of a submarine built by the Lake Co. for competition with the Electric Boat Co.'s submarine *Octopus*, now U. S. S. *C-1*.

This compartment was simply an air lock fitted with gauges, etc., in which a regularly equipped diver could equalize the outside pressure with air, and emerge. His air supply was furnished from the air tanks on board, reduced to the required pressure. Submarines thus equipped could pass through almost any channel, going below mines and obstructions, proceed and carry out the work mentioned with a good chance of success; the air lock, of course, to be used as a decompression chamber, so that once the diver returned there would be no time lost and the boat would be free to move. Air hose, life lines, and telephone cable could be arranged on reels, with shafts projecting through stuffing boxes into the boat, though in some cases the diver would require no attending.

Referring to (*b*) of paragraph (4), I would not advocate the installation of this compartment solely as a means of escape, for although the lower part of a submarine, where this compartment would probably be installed, is not as likely to be punctured or damaged as other parts of the boat, a submarine with no air in her tanks, or power to run pumps, could not make use of this method of escape. The conning towers of some submarines are supposed to provide a means of escape, and under certain conditions would probably suffice, especially in large boats with three or more water-tight compartments. It is submitted, however, that the conning tower is a projection and a part likely to be damaged or punctured. Furthermore, it is not believed that the present hatches are large enough to permit of a man passing through with a life preserver or so-called self-contained diving apparatus.

There is a certain hazard to duty on submarines which can not be overcome by providing means of escape, and first consideration should be given to means of improving and enlarging of their offensive qualities.

The question of deep diving enters largely into the subject of salving of submarines and crews. In August, 1904, the submarine *Porpoise*, with a crew of 12, of which I was one, was disabled and on the bottom in 160 feet of water, remaining there about 45 minutes. Since this incident it has occurred to me several times that with the present development of diving in the service we could have expected little assistance from sources outside the boat.

Immediately after this incident submarines were fitted with lifting pads, forbidden to operate submerged in all except moderate depths, etc. These restrictions have since been removed, and pads are no longer fitted, but it is believed that an air connection from outside to which a diver could attach a hose would be a desirable fitting in the case of a disabled boat. The lead inside could be taken through to the air manifolds direct to the tanks or compartments or other combinations made inside the boat. A diver would certainly be needed to pass slings under the sunken submarine, and deep diving should be developed in the Navy, for this, if for no other reason.

In conclusion I wish to state that, as you know, I am physically disqualified from diving and feel that this fact should be mentioned in case this letter should be read by other persons, in order that proper consideration be given to the suggestions, comments, and recommendations contained herein. Furthermore, I consider it not out of place to say that all incentive to serious thought and study of the subject of diving dates from my association with you aboard the *New Jersey*.

A. D. FRESHMAN.

U. S. S. "WISCONSIN,"
Navy Yard, Philadelphia, Pa., March 31, 1914.

From: Gunner A. E. Bentfeld, United States Navy.
To: Gunner G. D. Stillson, United States Navy.
Subject: Submarine armor, diving apparatus, appliances.

Your letter at hand and contents duly noted. Sorry, however, to inform you that I am not familiar with such work, never having had the opportunity to receive instruction in same, and am therefore of very little help to you.

A. E. BENTFELD.

U. S. S. "VESUVIUS,"
Navy Yard, Boston, Mass., April 1, 1914.

From: Gunner M. Macdonald, United States Navy.
To: Gunner G. D. Stillson, United States Navy.
Subject: Diving apparatus, as used in the United States Navy.

1. In reply to your letter relative to "Diving apparatus" I wish to state that I have nothing to suggest that would be either instructive or interesting to you; therefore, wishing you a complete success in your undertaking, I remain, as ever,

M. MACDONALD.

U. S. S. "ALABAMA,"
Navy Yard, Philadelphia, Pa., April 4, 1914.

From: Chief Gunner F. H. Whitney, United States Navy.
To: Gunner G. D. Stillson, United States Navy.
Subject: Submarine armor, diving apparatus, appliances diving operations, etc.

1. Your communication requesting suggestions for the improvement of diving appliances on board ship received.

2. As I have not had anything to do with diving in the last six or seven years, I consider that I am unable to make any criticism or offer any suggestions for improvements.

3. Any information which you may finally compile will be highly appreciated by me.

Trusting that you may meet with success in your undertaking, I remain,

Yours, respectfully,

FRANK H. WHITNEY.

EAST STROUDSBURG, MONROE COUNTY, PA.,
April 5, 1914.

MY DEAR STILLSON: Was placed on the retired list on January 13, 1914, for bad ears, resultant from diving and gunfire, but mostly from diving, I think, hence my recommendation relative to ear pain, as I guess I didn't stop when I should have. Am sending report or remarks as requested and would like to go more thoroughly in the matter, but the absence of a typewriter makes it a burden for me to pen so much. No doubt more experienced men than I are sending some dandy reports, and I hope you make your point and wish you every success in your undertaking, which is much needed by the service. If you have time, would like to hear any news you have, as regards experiments, tests, etc., and the general scheme.

Wish I could be there to help you, as time drags heavy on the shelf after being active, so if you ever need an assistant just mention my name—as I could easily enter into light, temporary duty—and being retired, would not be senior to you.

Again wishing you all kinds of success in your venture and trusting to hear from you, I am,

Sincerely,

T. C. WESTER.

East Stroudsburg, Monroe County, Pa., *April 5, 1914.*

From: Gunner T. C. Wester, United States Navy.
To: Gunner G. D. Stillson, United States Navy.
Subject: Diving apparatus, appliances, operations, etc.

1. There are forwarded herewith inclosures on the above subjects, as requested in your official letter of the 25th ultimo.

(*a*) Discarding use of present helmet and substituting one of bayonet joint design, with a lock-clip attachment to prevent helmet from working loose, or becoming turned and detached by fouling below. Experimental work with a suit made of tougher texture, say flexible wire-woven rubber or English waterproof fabric, which will give more resistance to cutting, puncture, and chafe. A thorough test of a practical, nonintricate means of telephone communication, eliminating external wires, by an adaption of a metallic circuit within the air hose, or a single circuit, with ground return, one wire in hose, other grounded to helmet; or exhaustive tests with a flexible wire of high tensile strength, interwoven with the life line, possibly using it as the heart of the line. This form of conductor naturally would have to be tested against strain, shear, nips, kinks, etc., but not against chafe, as the life line itself would protect it externally.

Shoes of variable weight. Sometimes a diver is encumbered with too much lead. Light shoes for light work, and according to the physique of the diver—some men are more buoyant and need more submergence weight. Remodel body weights so that they can be graduated, the units added or taken off at will, by some easily detachable method. Test out armored air hose, or hose of tougher and greater tensile strength than now used, in case it is imperative to raise a man by same, or if he has fouled his life line he can raise himself on same. A better quality of snappers should be procured and tested. The pad in the suit, for helmet rest, often gets wet, then hardens, and becomes a burden. An inflated pneumatic pad could be used, would be less bulky, and decrease weight of outfit. No comments on underwear or dungarees. Present form of knife seems O. K., except that in emergency it takes too long to unscrew it, and belt and holster seem unnecessarily heavy for knife. A bayonet catch would release knife instantly but would not be water-tight. Water-tightness is not essential if knife is kept clean at all times when not in use. No comment on present form of double acting pump, except that some provision could be made to increase volume of cooling water tank, especially for use in tropics.

(*b*) No comments. It is not believed that any set rules except those for signaling and safety can be adhered to—as no two operations are under like conditions, except perhaps, clean in fine weather.

(*c*) Covered by notations under (*a*) paragraph.

(*d*) Follow later.

(*e*) Divers under instruction usually suffer slight ear drum pain. Continued ear pain to a constant diver should be sufficient cause to compel him to stop diving indefinitely. To my mind, suggestions should be solicited from surgeons having had accident cases.

(*f*) This depends on the nature of the work and the condition of tide and clarity of water. For good conditions—moderate or no tide, good water, moderate temperature—an experienced diver should be able to do short shifts at recovery work between 90 and 110 feet of water. For emergency plunges, on an absolute certainty, say a depth not to exceed 140 feet with the present apparatus.

(*g*) By a more substantial type, for strength and protection to diver.

(*h*) To my mind this also is governed by conditions absolutely. A competent surgeon should be at hand, at all times, alongside diving, or diving from boats. In case of known danger a second diver can go down to stand by for emergency. I never sent a man down without one fully dressed and hooked up to a pump or spare pump, to go down to assist the man below, at a moments notice. In this connection, the matter of good telephonic communication becomes paramount for safety, as well as for rapid efficiency of operation. In very dangerous waters, with sharks, etc., where it is absolutely necessary to send a man down, a light charge of guncotton could be detonated before his descent, and repeated at intervals during his rest periods in the boat. In case of accident to a man below, where assistance is needed below, it seems that a type of helmet, with oxygen tanks, similar to those used by the Bureau of Mines, could be remodeled in a water-tight form, and an emergency man sent down in a very short time, using helmet and needed weights. This is rather a lengthy subject, but I believe that absolute authority by gunner in charge of diving, with perfect discipline and cooperation and no interference, will do as much for safety as any set rule.

(*i*) This question is not clear in my mind, whether you wish to discuss the relative merits of the "Bell" and "helmet" devices, or whether you mean the different merits of various types and manufactures. If the former, I am in favor of the present helmet type, with modifications as embodied in paragraph (*a*).

(*j*) No comments—never having had a school or class under instruction.

(*k*) This is a matter which should be settled by the consensus of opinion of a number of boards, keeping in mind not the return to be made for a man's services, but the value of his services to the Government, the nature of the work, and the danger, present and future, as regards the effect on his lungs, heart, ears, or general constitution. A diver may clean propellers—no depth, no danger—and take a day, four hours in the forenoon and four hours in the afternoon—which nets him $9.60. Another man may be sent overside at night to clean a steam engineering strainer or file a liner from a sluice-gate casting with an element of danger from inrushing water or suction, and may complete the job in 20 minutes. This nets him 40 cents; or, say he takes eight hours; he makes $9.60, the same as the first man. But the propeller man sat on the struts, in clear water, could see his work, and was in no danger, real or apparent. The second man had to hang on with one hand on a hogging line, under the bilges, or was held suspended near the sluice gate, in darkness, and had to feel his work. I will not say the first man did not earn his money, but I will say that the second man earned more. Then, again, the regulations state a man receives $1.20 an hour while submerged. Sometimes his hardest job is in coming up and hanging on to a stern ladder while a launch shifts her position. Surely this should be considered submergence time; and to that end it could be so made by having him keep his feet in the water. But that is straining a point, and I think the department would consider a revision of that article. When more than one man is down, or more than one boat used in joint operation, the gunner will be in the one where he thinks he is most needed. Responsibility devolves on a gunner's mate in the other boat for the life and safety of the other man or men down, and I think the other men in charge and the stand-by diver—fully dressed in either tropic heat or northern cold—and the tenders, should come in for some substantial remuneration. Sometimes, by a process of elimination through actual experience, the number of divers aboard ship dwindles down to a minimum, and these men alternate diving and tending, and split up when paid. But it is never a real "pay day." Cases occur when two divers work on opposite sides, under bilge turns, and work hard. They accomplish their end, and draw, possibly, several dollars each. For easier work the same two men may examine the strut, stern glands, etc., and receive the same money. A man may hunt a torpedo for a day, good bottom, easy going, and get nearly $10, while a second man may be sent to dig her out and close stop valve, put on propeller locks, etc., and get a scant $1.20 for an hour's work. The minimum rate for an hour's work for English helmet divers is about 60 cents, but I believe that old wage has gone up. Flooded-mine workers get about $10 a shift of 4 hours, with 30 minutes for dressing and undressing, for which they receive pay. In some salvage companies they receive $5 or more whether they dive or not. They are tenders and "stand-by" men. Some work by tides, getting $5 to $10 a tide while others work by a weekly wage of about $15 and extra for every hour down; others get a stated salary and a commission on the amount salved. In the case of the *Alphonso III*, off Point Gando, Grand Canary, in 163 feet of water, one diver recovered about three and one-half millions gold and received about $15,000 for the job, while his helper got about $5,000. In the case of the *Skyro*, sunk near Cape Finistran, silver was recovered valued at about $50,000, for which the diver received about $2,000 for the job. This is merely a commentary on the subject and is getting away from suggestions. The men should certainly receive pay more commensurate with the work and danger and more in equality with pay for similar work, in commercial salving companies. As stated before, I believe several boards should convene to fully consider, investigate, and report on this subject.

(*l*) Also governed by conditions. Have seen divers make 10 hours a day steady, and the same men could not work over 6 hours on other jobs under different conditions. Scraping propellers, clearing lines, examining underwater body, hunting torpedoes, etc., in good water under good conditions could be pursued easily at an eight-hour a day rate by good steady divers.

(*m*) Have not attempted to bunch original remarks or suggestions as they appear throughout.

(*n*) When the U. S. S. *Arkansas* grounded off the Cuban coast last year two divers immediately went over, examined the injury, one on each side, and reported. From their preliminary examination a very good estimate of the condition was obtained, and the vessel proceeded to Guantanamo. There efforts were made to stop several leaks and one large hole in the underwater body. The men were sent down on both sides at a certain frame and by their testimony a rough chart was made. They were then moved several frames aft at each shift and examined the underwater body from the water line over bilges to the keel, were brought up, and their testimony plotted on ship's plans. From these observations, in which the men were practically working from before breakfast to late at sunset, a detailed report and sketch was made which was used as evidence by the board of investigation.

On docking at the New York yard this information was extremely useful, as it was the first vessel of her size and type to enter the dock, and she was injured. The same divers ably assisted in her docking, which took some time, owing to the added features of precaution and investigation to determine whether her keel was buckled, and, if so, for the diver to drive shims or wedges thereunder. I can't remember what those men got, but it certainly was insignificant compared with their work.

In recovering torpedoes in Guantanamo we employed the use of hydroaeroplanes in the early morning to fly over the field and attempt to locate the missing torpedo, as their ability to see under clear water is very great. However, we subsequently found her by bubbles, after four days.

T. C. Wester,
Gunner, United States Navy, Retired.

U. S. S. "Kansas,"
At Sea, April 6, 1914.

From: Chief Gunner E. W. Furey, United States Navy.
To: Gunner G. D. Stillson, United States Navy.
Subject: Submarine armor, diving apparatus, appliances, diving operations, etc.
Reference: Your letter of the same subject:

In compliance with the above reference I hereby submit the following remarks, criticisms, and recommendations to questions enumerated under paragraph 5:

(*a*) The suit could be made quite a bit lighter in weight of material, but its durability or toughness should not be reduced thereby. The suit could be slit up the wrists and in front of the body and made to lace with a tongue, similar to a water-tight shoe. This improvement would aid in dressing and undressing, as a man's wrists would not be abused while getting in or out of a suit, and would expedite the drying of a suit after use. The breastplate could and should be made of a lighter material altogether. Some aluminum or some such metal would be advisable. Do away with the helmet cushion or "horse collar," as naval work is very seldom so lengthy or such heavy work as to require its use. Shoes should be made of cast steel in a sort of sandal form, with straps, which, I think, would be an advantage over the present shoe, which either rots or wrinkles up and becomes very cumbersome after a short period of use. Have heart-shaped weights suspended over shoulder and adjustable. When working in a stooping or lying position the present belt is exceedingly hard on the kidneys. Have the check valve placed farther toward the front of the helmet, as, in its present position, the suit must almost have to be made for a man in order to reach it. Hinge faceplate is suggested. Finger rubber gloves would be more suitable for this purpose than the present mitts. The pumps are entirely clumsy for the light work and average naval use, which is generally work of 100 feet or less. It is suggested that a handy billy pump be used when working in shallow water, although for either use the pump could be made much lighter.

(*b*) A platform for securing the pump in the bottom of the sailing launch would be most beneficial for heavy weather work. Three or four rungs of a chain Jacob's ladder can be made secure to the end of the iron ladder over the stern of the boat, also rails for this ladder to aid the diver in holding on while the helmet is being put on. This chain Jacob's ladder at the bottom would act as a warning to the diver in ascending, thereby preventing his helmet from striking on ladder or bottom of boat.

(*c*) Answered in (*a*). When cleaning propellers, strainers, intakes, or other shallow waterwork the suit is not necessary. Two metal straps on each side of the breastplate, forward and abaft of each arm, could be suspended down to the waist and formed into an eye, so that the belt could reave through and secure the apparatus to the waist. This arrangement would afford plenty of room for working and movement of the arms, and at the same time do away with the worry of the helmet getting away from you, and at the same time one could free himself by coming up on the buckle at the waist and stand clear to come up unaided.

(*d*) Be sure that the necessary gear for two divers are in the boat. The average man can dive four times per day without exerting himself, i. e., two-hour dips at 40 feet or under, one-hour dips from 40 to 80 feet, one-half-hour dips from 80 to 100 feet. It is not advisable to stay down much over one-half hour, unless the diver be exceptionally strong. One must be very careful in ascending and descending, if necessary, to stop every 5 feet or so, so as to become accustomed to the gradual increase of the pressure and depth of the water. In cold weather try the check valve before lowering into water, so as to be sure it is not frozen. It is advisable that the medical officer administer a small quantity of brandy to the diver after completion of his work. In cold weather 90 feet is a very good depth for any man to work in, but not for more than one-half hour. The tender should be a man of exceptional ability, and should be put through a special course of instruction, and should at all times know exactly what the diver is doing while submerged. He should never for a moment give the diver more than a few feet of slack on the life line, and if rough or choppy weather should have another man to back him up, so as to prevent the diver from dropping into a hole or off the propeller or stage. Being careless in lowering a diver, the life line is liable to get away from the tender, thereby dropping the diver to the bottom, which invariably results in his death. Too much care can not be given to this. No skylarking in diving launch at any time.

(*e*) Had no descending line and life line got away from the tender. If a man is pumped too fast and his helmet hits the bottom of the boat, he is liable to be affected with an earache. In the screw helmet the threads are apt to get crossed while putting on in a seaway, and cause a very bad leak. Pumps are liable to capsize in rough weather or the men be thrown away from the pump by the rolling of the boat.

(*f*) Eighty-five feet.

(*g*) The jock straps and crinoline relieve the pressure and aid work in deep diving, also have a three-cylinder pump and motor driven if necessary. For cold weather a hood is suggested for the diver's head and neck, as the cold air being forced against a man's neck plays havoc with his endurance, as it plays on one spot for an hour or more at a time.

(*h*) No mistaken system of signals. Require every man that does any diving or tending to know the dot and dash signals (Continental Morse Code). Warn the diver to rest frequently when working at a great depth.

(*i*) Morse.

(*j*) Before men are detailed for instruction in diving they should be examined as to their physical fitness by a medical officer, but as this is sometimes impracticable the following list of requirements and of physical defects which should cause rejection of men having them would be of great benefit to those who may be called upon to select candidates for this employment. Divers are—

To be cool-headed, calm, and of a phlegmatic temperament.

To be in good health and have a strong constitution, and be possessed with normal lung action.

Not to be short-necked, full-blooded, or possessed with a tendency to nose bleed.

Not to have blood-shot eyes or a high color on the cheeks caused by the interlacement of numerous small but distinct blood vessels.

Not to be very pale nor have lips more blue than red, nor to be subject to cold hands or feet, nor to perspire too freely.

Not to be affected with cough, cold, asthma, or catarrh.

Not to be subject to headaches, dizziness, or affected with deafness.

Not to be hard drinkers nor to have suffered frequently or severely from venereal disease, nor to have had sunstroke or rheumatism.

Not to have been subject to palpitation of the heart or fainting.

Never to have spat or coughed up blood.

Men who have long trunks with well-developed chests and loins generally make good divers.

After adhering to the above rules for the selection of men I would next teach them first aid for suffocation and resuscitation for the apparently drowned.

Next would be taught the International Morse Code of signals, which could be used in cipher to form a more thorough signal and understanding between the diver and attendant.

A tank should be constructed about 15 feet in depth and of a suitable diameter, to allow raising and lowering of diver and whatever other gear the instructor may think advisable for a candidate to work upon. Two or three port holes or peeps could be constructed at the bottom to allow the instructor to witness the diver's confidence, reliance, and general actions in handling himself, and in the use of tools under water. The wrench, Stillson or monkey, scraper, ax, saw, hammer, and a pinch bar are about all the tools necessary in ordinary diving.

Previous to being put into a suit each candidate is instructed thoroughly in the present method of dressing the diver. After proving his ability as a diver in the tank with the manipulation of tools the candidate should be taken out into deep tidewater and put through the proper way to buck a tide, ascend and descend from a boat, and also be given endurance or qualification dips in 40 to 80 feet depths. The dips should be of a duration of from one to two hours. The present system as laid down in the seaman gunner's "Manual for Diver" regarding signals, tender assistants, and dressers, etc., is thorough in every detail if adhered to.

(*k*) I suggest that divers be paid a certain amount for clearing propellers, strainers, and other known jobs. At 40 feet of water the pay of a diver should be $1.20 per hour and for greater depths $1.50 per hour. An hour's work constitutes 45 minutes under water and 15 minutes rest.

(*l*) In the tropics or hot weather six hours is or ought to be a good day's work; 5 hours in cold weather, and 4 hours in rough weather; let the diver decide. Under 40 feet, 6 hours; 40 to 50 feet, 5 hours; and from 50 to 70 feet, 4 hours.

(*m*) Have a standard make of oil for pump, such as 3 in 1, slightly scented with a mild perfume or menthol to overcome the offensive odor of the oil now used. A good idea is to have a box of chewing gum handy in the boat. If the diver chews gum while diving in deep water, it causes the diver to swallow occasionally, thereby relieving the pressure and causing his ear drums to release when the pressure causes pain. Have a first-aid packet in the boat for cuts, etc. Fit a piece of felt inside, at top, of faceplate to wipe off perspiration from the diver's forehead in warm water, or fit a sweatband around the diver's forehead. Have the diver's light so fitted that the light will not reflect in his eyes. Have the latest type of diving gear installed on ships. All new hose should be soaked in fresh water 24 hours before using. Mix together 1 part vaseline and 1 part tallow and apply on hand of divers before putting on gloves in severely cold weather. This is to protect the diver's hands. In unknown waters or in harbors be sure that the diver has a pole or staff in his hands before descending, the staff being used as a feeler, thereby preventing the diver from dropping off a bank or falling into an anchor hole.

E. A. H. FUREY.

INJURY OFFICE,
Navy Yard, Mare Island, Cal., April 6, 1914.

MY DEAR STILLSON: Your letter on the subject of diving came to me and thanks for the opportunity to put in a suggestion.

The most of our trouble in diving operations is due to the fact that we are away behind in appliances to enable the diver to talk direct to the surface. In my own experience I have often had, since being gunner, to get into a suit and do the work myself, where had I been able to telephone the diver who first tackled the job, he could have done it and saved time both for he and I. While on the *Maryland* I tried to use the 'phone we have on some of our outfits, but as you know the pump made so much noise that it was impossible for the diver to hear; to overcome this I tried putting a muffler, similar to those used on an automobile or a Maxim silencer, on the air hose at the pump connection, and had quite a little success. I think that if you try along that line it will not take much trouble to get a form of muffler that will be a complete success, and the result will be more safety for the man down and better control of the job and a general betterment in the temper of all the crowd in the business.

I think the above will cover items (*a*), (*b*), (*c*), and part of (*h*), in your letter; in reference to (*f*) I have found that some men can work deeper than others. I worked with quite a bunch of deep-water men at East Lamoine, Me. They were in the habit of working at between 150 and 180 feet. I never ran across any one who had been deeper. My experience with naval divers leads me to believe that with the few opportunities we have, we are not much good after we pass the 100-foot depth. This could be overcome with practice, but, unfortunately, we never have the chance to get that practice; when we have a wreck or a ship on the beach, instead of trying to use our own men to salvage it, wrecking companies are called in and we go ahead with the gun bright work or school or some other thing. If it could be done, I would have a complete wrecking outfit (large pontoons, tackles, heavy chain, etc.—we have cranes and tugs) at each navy yard, and every time there was an opportunity to get in on a wreck, whether our own ships or merchantmen, I would get that outfit to work. Of course that sounds far-fetched, but the Japs have exactly that, and with their outfits they sure got a substantial addition to their Navy in the China and in their Russian wars. In other words, they did not use it often but when they did it more than paid for itself.

There is a man in New York Navy Yard now who you might be interested in, he has been further under water than any man living, and he might be able to help you out; his name is Gamby, and he is a leading-man electrician; I would advise that you get him to give you any small pointers he may have. You can locate him in the power house of the yard.

H. McEvoy.

U. S. S. "Cumberland,"
Guantanamo Bay, Cuba, April 7, 1914.

Gunner G. D. Stillson, United States Navy.

Dear Sir: Your circular letter was received on the 5th instant. I regret being unable to offer any information which might be of value to you. Have not made a specialty of diving and consequently am in no position to criticize the present apparatus.

It has occurred to me, however, that if some genius could invent a safety attachment by which a diver could release himself from his suit, it would materially reduce the percentage of fatal accidents. The benefit of this is obvious in the event of a diver becoming fouled under water.

Very truly, yours,

John M. Lohman,
Chief Gunner, United States Navy.

Gunners' Workshop,
Washington Navy Yard, April 8, 1914.

My Dear Stillson: Your letter received and I will endeavor to answer as clearly as possible.

(*a*) Pump: Should be triple expansion, permanent fittings on sides of box to secure to permanent fittings in boat (no lashings to be used).

Suit: O. K., except that an extra size should be issued to the service for tall men.

Helmet: Should be of the interrupted-screw type, no telephones, and should have the exhaust valve on the right side and in front so that it can be operated by the diver without his trying to be an acrobat.

Shoes: To have large opening with only one strap around and above the ankle.

Belt: Do away with this abomination and use breast and back heart weights.

Hose: O. K.

Life line: To be of 3-inch, 4-stranded manila rope.

Descending line: Have one issued with outfit of 3-inch, 3-stranded manila.

Circulating line and weight: Have one issued to service of 18-thread manila and 100-pound mushroom anchor.

Ladder: Have one issued for each diving boat, as used at torpedo station.

(*b*) Gunner should be supreme in diving boat, no matter whether his superiors are present or not, unless the superior has taken a course and qualified, and then it should be understood before the diving party leaves the ship as to who is in charge. I state this because I have had the experience of fighting my superiors in regard to giving orders to divers. That is one thing I insist on when in a diving launch (no orders to be given to diver by anyone but myself).

No motor boat to be used for diving purposes, due to base or life line being caught in propeller.

The launch to have eyebolts in keel to secure pump to same with turnbuckles.

(*c*) No diver should be required to descend to a greater depth than 3 fathoms without a descending line.

(*d*) When the *Oregon* went on the rocks in the Gulf of Pechili, I made examination of bottom and found it pretty near impossible to get near the side of ship on account of the shear. Hogging lines were put over, but it was impossible to get close enough to work. I would suggest a stage, something like the cut inclosed.

Another thing that happened was this: The ship was on a ledge and as the water was being pumped out after plugging the holes the ship would rise and fall. The civilian diver who was working with me went down on the starboard side to see if any damage was done on that side; instead of coming up on the same side, he wanted to stuff waste in the tear in the port side. As luck would have it he had a lot of hose in his walking around on the bottom. I was just getting ready to take out all ammunition forward when I heard an awful yell from the executive officer to take off his faceplate. I was just in time to prevent a sad accident. I shouted not to take off the faceplate but to keep the pump going and I jumped into a boat alongside the ship. The man had gotten his hose caught between the ship and the ledge and pinched the hose, preventing his getting any air. He just had enough hose and line to reach the surface but not enough slack to take off the faceplate without his suit filling up. I immediately cut his hose, rolled him into the boat and took off his faceplate. He was bleeding profusely from his nose and mouth and his eyes were bulging out of his head. The suit was cut away and he was carried to the sick bay. He revived and was ready to continue his work in two days, but refused to go diving unless I tended him, which prevented my further diving on the ship.

I think a man should take his own time in descending, and 5 fathoms a minute ascending is what I have always been instructing. When descending too fast the blood rushes to the head and causes nosebleed or deafness. When ascending too fast the effect is headache and dizziness.

The time to remain under water at different depths should be left to the individual, as there are so many conditions to contend with in regard to the physique of the diver.

I have reached 20 fathoms in clear water with a sandy bottom and one of my men reached 21 fathoms with muddy bottom and worked 10 minutes reeving a line through anchor shackle.

The pressure is great without the pressure belt, and in using the pressure belt it is too cumbersome.

(*e*) The only accident I have experienced was due to the pump moving while launch was rolling in heavy swell. The handles were caught in lashings and pump had to be stopped for about 20 seconds. See report on securing pump in launch.

(*f*) I should say not more than 20 fathoms.

(*g*) At great depths it is too exerting to pump with a compound pump, and when diving in a tideway it is impossible to distinguish the signals on life line or hose unless the diver exerts all his strength in the pull. I would suggest that a thoroughly insulated wire be laid in the life line with the battery in boat and a push button and water-tight buzzer on each end. This should be the means of signaling in a tideway.

(*h*) Have nobody in launch except graduated divers, one man to be supreme and take all responsibility, no matter who is in the boat and who is senior. The whole secret in diving is to have confidence in the man in charge and when the divers know that they are looked out for while under water the operation becomes pleasant and useful instead of a burden and waste of time. If the work is long and hard, a spar buoy with red flag should be placed on four corners to keep boats and one in launch a per sketch.

(*i*) I consider the English outfit as used at torpedo station the best interrupted screw helmet, heart breast weights, and triple pump.

(*j*) The school for divers should be started in Quantanamo when the fleet is there. There is no use wasting time in schooling divers when the ships are in their home ports unless the stay is long and the first instruction has been completed. The candidates should be picked by the diving officer. They should be examined by the doctor and when pronounced fit, the instruction should start.

1. Teach the names of all parts of diving outfit, assembling and dismounting, dress and undressing, and signals.

2. Take class to sloping sandy beach and after being dressed let them walk out until their heads are below water. This to get used to the lonesomeness and sound of the pump, including instructions in signals under water.

3. Send them down in 5 fathoms and increase the depth 5 fathoms after every three lessons until 20 fathoms are reached.

4. After qualifying at the depth, some article of no real value should be dropped overboard, and the candidate must recover same by circulating with line before graduating.

(*k*) The pay of divers should be 5 cents per minute from the time the diver begins to dress, but it should not take longer than 10 minutes to dress and 5 minutes to undress. I deem the dressing harder than the diving.

(*l*) I would say four hours should constitute a day's work no matter what climate, or location, but when diving at great depths breathing spell should be allowed. "Ten minutes to every hour."

(*m*) No request from the diving officer in regard to boats being used should be questioned, as the life of a man under water is in the hands of the diving officer who should be held responsible at all times.

The location for stowing outfit should be left with the diving officer, not put where the suit or hose will rot when it is warm or too damp.

S. JACOBS.

U. S. S. "TEXAS,"
Navy Yard, New York, April 9, 1914.

MY DEAR STILLSON: Your letter regarding diving, diving equipment, etc., received some few days ago and this is my first opportunity to acknowledge its receipt.

I regret to say that I am in no position to give you any authoritative information that would be of service to you regarding the subject referred to, as my experience along those lines has been limited to that of ordinary service requirements.

I may say however, that all diving operations of which I have been connected, have been successful, in that the desired results were obtained.

The equipment and personnel seemed always, to me, to be satisfactory, but as I have said before, my experience has been too limited to qualify me as an authority on the subject.

I trust that your new venture may prove successful and I have no doubt that it will, and wishing you, personally, every success I am,

Sincerely, C. H. ANDERSON.

U. S. S. "PITTSBURGH,"
Bremerton, Wash., April 12, 1914.

From: J. Harder, gunner, United States Navy.
To: Gunner Stillson, United States Navy, in charge of diving experimental station.

1. In compliance with your letter, I respectfully submit the following experiences I have had on diving for your information should you find same to be of any importance:

First. I wish to frankly state that previous to my being appointed a gunner I had very little experience as a diver, but since then, while serving on board this ship, I have conducted several experiments for my own satisfaction. They are mainly as follows:

(1) Two divers using one pump, shallow water.
(2) Two divers using one pump, deep water.

(3) One diver using one pump, deep water.
(4) One diver using two pumps, deep water.
(5) Controlling a diver in a heavy tide.
(6) Method of searching in deep water.
(7) Cause of diver becoming unconscious.
(8) Preparations and method of handling divers.

Before answering your questions, I will first explain the above itemized experiences:

(1) The case of two divers using one pump especially in shallow water (not over 7 fathoms) has the following advantages: (*a*) Covers a greater area for the allowed period of time. (*b*) More divers under training. (*c*) More pay for the divers. (*d*) Increasing the chances of recovering the object searched for. The method used in keeping divers clear of one another is by measuring the radius line so that the divers just meet. The circling weight was carried out and planted for a dinghy. To keep the diver clear of the anchor in circling, the anchor was used as a pivot for the circle covering the forward part, cautioning the diver to reverse direction after completing each circle so as not to foul the anchor chain. After covering this area on each side, forward and after end of the boat (assuming the boat to head true north), shift anchorage 45° from north or south (the distance equal to about the diameter of each circle described) toward the direction you would most probably find the object searched for. If not found continue searching in these 45° directions from the first anchorage.

(2) Two divers using one pump, deep water (13 fathoms), is hardly advisable, for reasons of insufficient air supply due to loss in leakages, the danger of not being able to haul up a diver quickly in case of an accident, as the time for decompression from that depth, after being down three-fourths hour, requires a period of 32 minutes, according to the tabulated list for decompression from three-fourths to 1¼ hours. However, the person in charge can use his own discretion, depending on the conditions, time for diving, experience of divers, tide, weather, traffic, etc.

(3) In this case I have been fortunate enough to continue diving until I discovered the cause of unconsciousness and a remedy for same. I found that one pump can not supply the required air for the average Navy diver at a depth of over 100 feet. I also found that any variation in the air supply, especially that which caused a reduction of air, immediately caused unconsciousness. The diver in attempting to signal for more air and using this exertion immediately induces unconsciousness. Another cause is due to the men at the pump cranks "pausing" during certain parts of the revolution, which in turn momentarily stops the air supply. From the above lack of air supply I recommend that two pumps should always be used in diving at this depth. The benefit derived therefrom is obvious. In deep-water diving, signalling must be reduced to the minimum. The pull required to transmit a signal from the diver to the tender requires an undue exertion (deep water), which in turn induces exhaustion. Then, again, the twisting of the air hose and life line causes a signal to be transmitted through both. In this case a signal on the life line for "all right" immediately causes an increase in the air supply, due to the hose being fouled with the life line. Another cause, when diving in a strong tide the amount of hose paid out causes a vibration which confuses the tender and at times fails to acknowledge the diver's signals. I therefore urge that some other means of signalling be adopted. I have never had the opportunity to test the telephone system, but in spite of the complaints of its use I think it far better than the life line and hose system. I believe if enough experiments be carried out with telephones improvements can be discovered to remedy present faults.

(4) The case of one diver using two pumps is the most satisfactory method I have ever used, and not saying that one is not capable of supplying the required amount of air, but better results can be obtained from two pumps, namely, the following: (1) The supply is from four cylinders; (2) the supply is constant, making breathing con-

ditions practically "normal"; (3) less chances of stopping air supply due to "pausing" at the cranks during the revolutions; (4) two pumps ready for use in case of a second diver having to be sent down, where with one pump it would be practically impossible; (5) a reduction in the number of revolutions requiring less men for reliefs at the pump cranks; (6) one pump is available in case of a breakdown in either pump; (7) a cooler air supply from the reduced friction and heating of cylinders, due to the reduction in the number of revolutions; (8) a diver can remain under water more than twice the length of time possible when using one pump.

The only disadvantage is the danger of giving the diver too much air and blowing him up, but this case can be easily guarded against; also that of a diver remaining under the water too long and not allowed the correct time for decompression during ascent.

7. The control of a diver under water depends entirely upon the experience of the diver. The average diver under water is practically lost regarding direction or distance covered. I again urge the use of telephones. In a strong tideway where the diver is not able to remain on bottom I used an anchor and line, the diver lying flat on the bottom and pulling himself toward the anchor, also being able to search a few feet on each side. This method is satisfactory in a strong tideway where the location of the object is known, dropping the anchor a few feet ahead of the object. The use of extra weights is also suggested, strapping a boat anchor on the diver, but could not find any one that was in favor of the scheme.

8. In preparing a diver "confidence" in the personnel, material used, and the surrounding conditions must be impressed on each diver. He must be informed of all the defects that are known and remedied, and must be assured that everything is in good working order. His dress must be a comfortable fit and not leaky. A diver not comfortable in his suit will be at a disadvantage, and it will only be a loss of time to send him down, as he will not last long. A safe way of lowering or hoisting a diver in a seaway is by having a davit fitted in the afterend of the boat, having a cleat fitted with a sheave or roller to reduce friction on rope in hoisting; also used to give and take slack line while the boat is pitching to prevent "jolting" the diver. This davit is also to keep the diver from being hit with the ladder or keel during ascent or descent. I wish to call your attention to the necessity of a davit over the boat stern. I had the experience of lowering a diver in a heavy seaway and his helmet was in danger of being crushed by being struck by the boat's keel. This seaway was so heavy that the boat struck the propeller blade and broke her keel. From this you could just imagine the danger of a diver being directly under the boat.

(*a*) Mentioned in previous statement.

(*b*) A routine of diving should be carried out the same as for other drills on board the ship and reports submitted of the results.

A more severe test be for the qualification of divers. Stations for the instruction of divers should be provided with the means for the proper training of divers on such work as may take place on ships at sea, such as patching up a hole after a collision, recovering dead bodies, digging a hole to recover a torpedo that has bored its way into soft ground, etc. The above work could be provided and candidates made to perform such duties under water.

(*c*) Covered in items following.

(*d*) A method of searching was suggested to me by Lieut. Commander F. N. Freeman, was tried off Coronado Island, Cal., and proved very successful in searching for a torpedo lost in a depth of 112 feet. This method consists of towing the diver over the ground searched with a dinghy, which gave the diver no work whatever under water and covered more ground in less time. The ground covered was not gone over twice, as a circle of buoys was used to mark the ground being searched and the bearings. The dinghy was successful while it was calm, but when it got too rough the work was too much for the boat crew. I then used the steam launch. The sailing launch carrying the pump and party was towed by the steam launch, a short painter was used with plenty of slack for paying out, and a man stationed at the painter for this purpose also standing by the anchor. Astern the hose and life line was coiled with plenty of slack line used both in the bow and stern. We never had such headway that it was neessary to use these precautions, but it must always be kept in mind to be used in case of a failure to stop the steam launch and all slack line payed out. At first no diver has confidence in this method. For this reason the dinghy must first be used, and after becoming accustomed his desire is to be towed faster. In this case the steam launch is used. The speed being about one-fourth speed, the diver could adjust the towline so that he could be towed over the ground at an angle depending on the kind of bottom. The towline had a grate bar secured to its end. The diver placed this bar under his arms and simply kept his arms in a folded position while being towed. The diver in this position was very comfortable. One diver was towed in this position for over two hours without any trouble.

This method of searching was also tried previous to this by Lieut. Commander F. N. Freeman while in command of a torpedo boat; so it therefore proves a success, and I think it the only method for searching in deep water.

It is suggested that during meal hours the diving party be not allowed to throw scraps overboard after meals, as this at times attracts schools of large fish. One of my divers came up in a very excitable condition and said that he mistook a large fish for a torpedo, and demanded that he be given a knife. However, that ended his diving for that day.

(*d*) In the case explained in (*c*) we used eight sections of hose, and it seems at this depth there was a considerable leakage through the couplings. This leakage dripped directly on the diver's head and made it very uncomfortable. This can be remedied by taping the couplings and any hose that showed cracks on the outer skin should be condemned. This takes place at the part connected to the helmet. It therefore proves that the present coupling is not a water-tight coupling. The suit is very uncomfortable, due to the uneven distribution of weight. In such cases where a diver is dressed standing by to relieve the one that has descended, he is practically tired long before he relieves the other diver, due to this enormous and unequally distributed weight. I suggest that all weights be made detachable so that a diver can be dressed without carrying this weight until ready to descend. The shoes are not large enough to allow some men to use socks. The toe should be capped about 2 inches over the top, as this part is generally the one used most and first to wear out. The lead belt should be discarded and some other form of weight that can be easily added to the suit used. Something should be added to the suit to relieve the water pressure from the stomach, the weights being removed from around this part of the body and applied anywhere from the shoulders down to the chest and from the hips down. I think a weight around the legs in the form of a pair of leggings fitting snugly would be a great improvement. A davit over the stern of the boat for lowering the diver would be a great improvement and should be fitted to all launches. This would eliminate the danger of a diver striking his helmet against the boat's keel. A diving party should never leave a ship without having gear enough to use upon two divers at the same time; this is in case the first gets fouled, etc. In shallow water a diver can be allowed to descend as often as he desires, but in deep water it is not advisable to allow a diver to remain below over one hour. The diver that I had down in 112 feet of water had no desire to go down for one and one-half days afterwards, although he stayed down this period of his own accord. This man was the best diver we had on the ship. He was not a seaman gunner and had no previous experience, simply volunteering, and was examined by the doctor and pronounced physically fit to perform this duty. After this experience no diver was allowed to stay below more than one hour; he was then always available for a relief. I think that four hours would be the maximum period for a day's diving (deep water) in shifts of one hour. This shifting would prevent any injury to his health, and though he desired to remain below a longer period he should not be allowed. In using this hourly shift I used these men for three days after the first experience of the two-hour period. One man broke out in pimples, which I put to the lack of decompression. I have great faith in decompression after this case, even though it is very uncomfortable for a diver to have to wait at the different stages.

(*e*) I had one case of a diver being blown while scraping the propellers; this was due to the exhaust valve sticking in the closed position. This helmet was used a few days before this in searching for a body drowned near the beach. There was a strong current along the beach which caused a heavy circulation of sand; this sand settled on the valve and a particle worked in the valve stem and caused it to stick. The valve functioned for about 20 minutes with the diver submerged before it stuck. I therefore advise that the valve be removed each time before descending, specially diving in sandy water. I also recommend a cooling attachment to the pump for keeping the cylinder cool. Something in the form of a water pump with a hose suction from over the side, also a discharge. It is impossible to carry enough ice or cold water to last all day in the Tropics. An additional pump could be easily connected to the crank and would not occupy much space.

(*f*) One hundred and twenty feet.

(*g*) By furnishing a four-cylinder double-acting pump and a suit to stand the pressure and to relieve the pressure from the diver's stomach.

(*h*) Misunderstanding of signals. I suggest that the regulation form of signals be printed on a plate in white letters and this plate be fitted and secured to the helmet in front of the diver's face, so that he can always be sure of the proper signals; this is, in the cases of inexperienced divers. The adoption of telephones would eliminate this danger.

(*i*) Given in previous items.

(*j*) I suggest that schools for the instruction of divers be organized at each training station, navy yard, and whatever ships available. Reasons are that while located at these stations they can be best spared from other duties; quarter available; and surgeons are available for physical examination during the progress of their course, and the means for improving their mechanical ability can be provided with hardly any extra expense to the Government. The most important feature in the training of divers is in the selection of men for such duties. The class to commence with lectures on diving; to handle all dead bodies in the vicinity; witness all surgical operations so that they become accustomed to the handling of such work at sea; study the remedies for all accidents that may take place in diving, etc.; books to be furnished the class to study on the above subjects.

The mechanical course can be alternated with the diving course. At the completion of this course the candidates be transferred to sea to continue their course in diving in different waters and climates, and continue this practice at regular period; this would keep them in condition for any such diving that would endanger their health without this practice.

(*k*) A skilled diver should be paid $20 a month regardless whether or not he does any diving. This qualification must be accepted of his own free will, and after acceptance he can be compelled to perform this duty at all times instead of volunteering. He is to be examined monthly as to his physical condition, and should he not prove fit should be disqualified and the extra compensation should cease until such time as he may again be pronounced fit, regardless of the cause of his disqualification.

The number of qualified divers should be limited in accordance with the ship's complement, I should judge about six on a battleship, four on a cruiser, two on each flotilla, etc., no less than two in any group of ships. The above scale of pay renders the chances of the diver and the Government even, for a diver on the outside, in civilian life, is paid $5 per day; from this he has to pay his board and lodge, etc. I therefore think that $20 a month for a qualified diver is ample pay considering all other expenses paid by the Government.

(*l*) Mentioned in previous items.

Suggestions.—The use of air hose be limited to certain periods. That the date of commencing the use of an air hose be stamped on the coupling and be discarded after the expiration of such period. There has been no record given as to the life of a hose and this should be found. In fact the use of any gear that involves any danger should be limited.

The air connection should be so fitted that in case of a diver being foul and unable to clear himself without cutting the hose, the suit should be pumped full of air, the exhaust valve being closed immediately; upon the diver starting toward the surface he should disconnect his hose and float to the top where he can be picked up by the party.

No diver should be allowed to descend without another ready to relieve or assist him at a moment's notice. The party never to leave the ship without enough gear for the use of two divers at any moment. Instruction in dynamiting should be given to divers at the school.

A relief valve of some sort should be fitted to the helmet to prevent floating; a valve that would open should the pressure in the suit reach that capacity that would cause the diver to float. This valve can be made in the form of a balanced pressure valve.

A "T" connection can be made, the end (*a*) screwed to the helmet, the end (*b*) the main air hose, the end (*c*) the short length of hose carrying the relief valve. The valve so constructed on descending that it can be screwed up and out of action; on reaching bottom the diver can adjust the spring to hold the valve seated against the water pressure at that depth, and should the diver float, the valve now having a difference of pressure will automatically open and allow excess air to escape and the diver will in turn descend to the bottom due to this valve alone. This would prevent the sudden exposure of the diver to a difference of pressure and resulting dangers.

J. HARDER.

U. S. S. "PADUCAH," SURVEY GROUNDS,
Tunas de Zaza, Cuba, April 13, 1914.

To: Gunner G. D. Stillson, United States Navy.
Subject: Accident with diving apparatus.

1. In reply to your letter of March 6, 1914, I believe that information which will be useful to you can best be obtained from the record of either the "board of inquest" or the "court of inquiry" in the case of the drowning of the late William F. Hill, chief gunner's mate, United States Navy, of this ship. The matter was gone into very thoroughly by these boards and the details of the accident appear in the record. It is, therefore, suggested that you request the department to send you a copy of either of the records. The documents are:

"Record of proceedings of a board of inquest convened on board the U. S. S. *Paducah* in the case of William F. Hill, chief gunner's mate, United States Navy, dated December 12, 1913," and

"Record of proceedings of a court of inquiry convened on board the U. S. S. *Paducah* to inquire into the circumstances attending the death of William F. Hill, late chief gunner's mate, United States Navy, dated February 9, 1914."

2. The answers to your questions are as follows:

(*a*) In the helmet and underwear only. Hose led under diver's arm. No diving shoes, suit, or weights. Life line led to bowline around waist.

(*b*) A. J. Morse, No. 1292, two-valve inlet and outlet.

(*c*) No dress.

(*d*) Only the helmet was used, and under these circumstances the pressure can not become too great. The safety valve was not tested.

(*e*) Pump was tested by plugging discharge to see if it would hold pressure. A. J. Morse, No. 1.

(*f*) Telephone was not used. None has been supplied the ship.

(*g*) Yes.

(*h*) There were no leaks. The complete outfit was tested by connecting up the helmet with the pump, lowering it overboard and pumping through.

(*i*) Twenty-seven turns per minute.

(*j*) Not estimated.

(*k* and *l*) See report of "board of inquest" or court of inquiry.

(*m*) The safety of the ship may depend on the diver. Diving apparatus supplied to this ship seems satisfactory except telephone should be supplied with it and two helmets so that, as in the case of Hill, if the diver down gets in trouble another can be sent to his rescue. Further, a second helmet would also be useful as a spare, in case of damage to the helmet in use.

U. S. S. "WASHINGTON," *April 15, 1914.*

MY DEAR STILLSON: Your letter relative to diving appliances and operations received. It has taken me some time to answer all of your questions, and believe that I have fully done so.

The standard make of diving outfits—Schrader and Morse—that are furnished to the naval service, if kept in good condition, will answer all the conditions of the service for which they are furnished; there may arise special cases where it is desired to descend to great depths, and it is to that end that I make the following suggestions, which will, I think, improve the outfit at a very slight increase in cost.

The pump.—Have all bolts and nuts fitted with a locking device or cotter pins; increase the length of the crank handles to 2 feet and have handles secure to crank shaft with a spring catch in addition to the lock nut now provided; increase the weight of the fly wheels one half; stiffen the pump frame and have rings for securing pump to the deck attached to the pump frame for additional stiffening; chamfer slightly the top of the air cylinders to facilitate entering the piston-head packing; make the sides of the pump box portable for accessibility in overhauling the pump; have posted in the lid of the pump box and covered with some suitable transparent material for protection instruction for the care and management of the pump and outfit, the time for decompression due to depth of water and length of time down; have all spare parts secured to the inside of the pump box, the piston head packing (spare) to be put in tin boxes to prevent injury and to keep soft.

The dress.—The diving dress should have additional pieces sewed on each side of the legs, with brass eyelets for lacing up the legs of the suit to prevent the diver from being forced to the surface due to air getting into the legs of the suit, a very dangerous thing if in deep water.

The helmet.—The helmet should have a "spit cock" attached for use in regulating the air pressure within the suit and for use in regulating the air pressure when the diver has work lying on his back. The telephone receiver should be the loudest sounding that can be secured so that a conversation can be carried on above the noise of the pump valves; if found necessary a water-tight push button could be installed and operated by the diver's chin for a call bell. All helmets should have the joint between the helmet and breastplate of the interrupted screw type; the advantage is that the helmet is put on quickly and does not get out of order; a further advantage is that if the apron gets caught it is known right away and not after a diver has entered the water.

The life line.—The life line should be of 2-inch manila, with the telephone cable as the heart, and not less than 250 feet in length. The only objection to the telephone cable being the heart of the life line is the liability of the insulation to rot. This is more than balanced by the liability of the telephone cable becoming foul, which causes some divers to get excited and to lose their head.

Air hose.—The air hose before acceptance should withstand an internal pressure of at least 125 pounds and at the same time a pulling strain of at least 200 pounds. It has been suggested that the telephone cable be installed within the air hose. This is quite practicable and would be better than the life line.

Diving shoes.—The diving shoe soles should be of cast brass, with toe caps.

Weights.—The breast weights should be used instead of belt weights. They are more easily adjusted and cost less.

Omit from the diving outfit the crinoline and urinal. Furnish a 5-way connection for connecting up two or more diving pumps; four lengths of air hose each 15 feet long, with female connections on each end, for use in connecting up pumps for deep-water diving. Storage batteries should replace the dry cells for use with the telephones. The dry cells deteriorate, due to local action, while storage batteries can be kept in good condition at all times.

Diving launch.—Each ship should have one sailing launch fitted especially for conducting diving operations. To this end the launch should be fitted with pads for receiving the diving pump and ladder toe. The anchors (two) should not be less than 150 pounds each, with at least 300 feet of chain to each anchor. The diving ladder should be made of iron, with iron braces. Each launch should have at least six 75-pound weights for use in anchoring buoys and for descending line.

Divers.—Attached to each vessel there should be at least six qualified divers, and the fact that they are qualified divers noted on a page of their "enlistment record," these men to have charge of the diving outfit aboard ship and the smoke helmet, and will compose the diving party at all times. The pay for these qualified divers should be an additional $1 per month so long as he remains physically qualified for diving. Every qualified diver should be examined each year and required to descend to a depth of 150 feet, after which his certificate shall be renewed for another year, and he shall not lose the same except when physically unable to go down, due to some act of his own, or refuses to go down when ordered. A man who has refused to go down shall not be allowed to qualify again.

When a diver is actually engaged in diving, not for instruction or drill, he shall be paid $1.20 per hour, the time to count from the time the helmet is put on until the helmet is taken off; and the time that a diver remains hanging on a ladder while a boat or staging is being shifted shall not be deducted from his time unless it takes more than one-half hour, in which case the diver should have been taken into the boat and his helmet taken off.

The length of time a diver can remain down depends on the diver's physique, the depth of water, nature of the work, and the tide. Up to 60 feet he can go down as quick as he likes and remain as long as he likes, but beyond that depth he has to be careful. He must not stay down too long, and the longer he remains down the more thoroughly his blood becomes saturated with air and the longer it will take him to ascend.

The most sensation that a diver is likely to experience is in the case of a too rapid ascent. He may descend as quickly as the pumps can supply the air; coming up is quite a different thing. This is because of a curious action that takes place in the blood. When a diver descends, the air pressure within the suit is increased in proportion to the depth; some of the air is absorbed by the blood, and the blood continues to absorb air as long as the diver remains under pressure. As soon as the diver starts to come up the air begins to bubble out. If this takes place gradually, no harm is done, but if it were to occur quickly bubbles would collect in the artery branches and in the heart, causing illness, paralysis, and probably death.

The British Admiralty have made very exhaustive tests in diving at different depths and have drawn up tables for the guidance of divers and their tenders, and I believe the working depth given is about 200 feet and the maximum depth at about 230 feet. The time that a diver can remain down at these depths is so very short that no practical work could be accomplished, while the time for the ascent would be nearly 3 hours if the diver was down 10 minutes.

Relative to starting a diving class, I think that you are doing very well along that line, and it is one of the best things the Navy Department has done, as it will put into the service a lot of divers that will be qualified for any work that the Navy Department may require. As you probably expect me to write something on the subject, I will make the following suggestions:

All candidates should be selected for their physique and mechanical ability, and that they also be torpedo gunner's mates, gunner's mates first class, or chief gunner's mates. The reason for this selection is that vessels having torpedoes require the services of a diver more frequently than any other ship, and a ship supplied with torpedoes should receive a crew of gunner's mates (torpedo) who are (if the suggestion is followed) qualified divers. The instructions should be the care and management of the diving outfit; the different times for ascent, due to time down and depth of water; the effect of the tide; to send a man down again that has been brought up in a state of collapse, due to a too rapid ascent; the trust that is placed in a diver's tender by the diver to see that he does not remain down too long and that he is brought to the surface correctly. It is also important that all qualified divers be familiar with the different types of smoke outfits furnished to the ships.

It is very hard to say what can be considered a day's work for a diver, as everything depends on the condition of the weather, tide, depth of water, and the diver's endurance. My opinion is that if a diver remained under water for two or three hours at a depth of 50 to 70 feet it should be considered a day's work, and for the good of the diver I would not permit him to go down again, except in an urgent case.

In conclusion I must say that I have not been present at any accidents, and as far as I can judge most, if not all, that I have heard of could have been avoided if the diver or his tender had not lost their heads. The safety of a diver and his only protection is the care of his outfit and the watchfulness of his assistants.

Very truly,

E. N. Fisher.

Department of Electrical Engineering,
Naval Academy, Annapolis, Md., April 15, 1914.

Gunner Stillson:

Dear Sir: Am in receipt of communication from you regarding diving apparatus, etc., and I regret to say that I don't know enough about the subject to talk intelligently on it.

I have no personal experience in diving, neither have I ever handled any diver, so you can see my knowledge is limited.

Am very sorry I can not help you in this matter.

Very respectfully,

R. O. Williams.

U. S. S. "Pittsburgh,"
Bremerton, Wash., April 16, 1914.

Gunner G. D. Stillson.

Dear Sir: Your letter on diving operations, etc., received and contents noted. I am, in turn, compiling the information requested,. and it would require several weeks to complete same. Kindly let me know if you have the information given in the Naval Hygiene; if not, I will forward with my letter "extracts" that I found most useful. Should you have same let me know. It will save a lot of unnecessary work. Trusting you be successful in your duties,

I remain, sincerely,

JOHN HARDER,
Ordnance Gunner, United States Navy.

NAVY YARD,
Philadelphia, Pa., April 16, 1914.

From: Chief Gunner Joseph Hill, United States Navy.
To: Gunner G. D. Stillson, United States Navy.
Subject: Submarine armor, diving apparatus, appliances, diving operations, etc.

1. Your circular letter on diving reached me on my recent return from leave of absence, hence the delay in answering.

2. As my personal experience in diving has been very limited in recent years, I regret being unable to add any useful information on the subject.

3. I believe the diving gear now on ships of the Navy should be so modified or be replaced by such improved apparatus as would enable the average diver to safely descend and perform useful work in depths up to two or three hundred feet of water.

JOSEPH L. HILL.

U. S. S. "HANCOCK,"
Off Tampico, Mexico, April 20, 1914.

From: Gunner Charles H. Foster, United States Navy.
To: Gunner G. D. Stillson, United States Navy.
Subject: Diving and diving outfit; suggested improvements.

1. *Life line.*—To encourage the diver, private concerns use much heavier and stronger life lines. Owing to the weight the life lines are required to hold, the above would insure safety to the diver and be more seamanlike. I also suggest a flat sennet belt made up like a saddle girth and fitted with a ring and snap hook, having the life line spliced into the ring, the idea being to relieve the present manner of having a 21 or 24 manila line from hurting the diver when a strain is on it. This happens frequently when hauling the diver out of mud and raising or lowering in deep water. Cable-laid rope of average size would be more serviceable. In my opinion the life line should be graduated in fathom lengths by different-colored bunting tucked between the strands, these graduations to be used for approximate checking with the depth gauge; i. e., if gauge fails to function, or in case diver is uanvoidably shifted from working position after the life line had become fouled; in checking the difference between the life-line mark and the depth gauge it would only be natural to assume that there was trouble. For example, a diver's life line is fouled around propeller blade, leaving sufficient slack to permit his falling, the tender would not be cognizant of this accident, but by the suggested improvement the accident would soon be discovered.

2. *Making preparations for diver to work off bottom, as on propellers, strainers, etc.*—To insure the diver from falling from his place of work, such as the hog in line when cleaning strainers, etc., have an iron hatch grating bridled and place where the diver can sit or stand on it. This should prevent falling and also allow him to work with both hands.

3. *Protection for diver.*—To insure the diver against attacks by sharks (extract from British Service Magazine) it is recommended that a wire meshing, one-eighth inch,

curved to fit over limbs, one from knee down, one around thigh, one around body, one around biceps, and one around fore arm, all to be linked together with a free movement. This to be used in shark-infested waters.

4. *Helmet.*—Valve in helmet should be easier to reach. When suit is full of air the average diver can not reach the valve to operate the exhaust. Fixture to hold wet sponge fitted inside helmet for moistening mouth and lips of diver.

5. *Improvements to pump.*—When a diver is working in 30 or more feet of water the pump is difficult for two men to operate, owing to the pressure required at that depth to overcome the exterior pressure. This causes early fatigue. I suggest that a portable addition be made to the handles to enable four men to supply air instead of two; or gears can be fitted on the outside of pump casing on the principle of high-geared bicycle, one on outboard end of crank shaft, which in turn would gear into a larger one supported by a shaft and bracket which carries the crank.

6. *Transporting pump on board vessels.*—In case of a collision the diving pump may be located in a remote part of the ship, and great delay is experienced in getting pump to the scene of action. The pump casing could be equipped with four (two on each side), inverted flat metal U hooks for the purpose of inserting piping or bar for lifting and carrying (sedan-chair style). The piping or bars to be of a length and placed at a sufficient height to prevent the lower limbs of the carriers from striking the pump case. A rolling transporting arrangement similar to that on a Burroughs adding-machine stand, used in conjunction with the above, would expedite transportation. The piping or bars to be used for lifting the pump over water-tight doorsills, etc., and the rolling arrangement for running along decks. The wheels to be of flat type, with corresponding rubber tires. By means of a crank system the wheels are raised when not in use, thus allowing the pump to be stationary when in use. With these attachments the clearance when passing pump through doors, etc., would not be added to. Either of the above can be used as a unit or together.

7. *Revolution indicator.*—To keep pump men posted as to the proper speed, a small indicator could be placed on the pump to register the number of turns necessary for any depth. When the diver signals O. K., the pump men consult the register and are guided by the supply indicated. This idea would overcome a tendency to slow down from fatigue, the present depth and pressure gauge being out of sight.

8. I suggest that a glass front tank (enlarge aquarium type) be installed indoors at the Seaman Gunner Classes both at Washington, D. C., and Newport, R. I., for the purpose of instruction and demonstration of the different methods of approaching and executing underwater work, and the general manipulation of the life line when relieving a diver in distress, and the school of self-preservation during the time of casualties.

9. *Diver's suit.*—I suggest that a jacket made of the same material as the suit and yoked by straps under the crotch, and fitted to receive the helmet as on a full length suit, be adopted for the purpose of relieving the inconvenience now experienced when using the helmet without the suit. This is lashed with cordage under the arms and has been used for shallow water diving, such as clearing propellers, etc., and entails a dangerous proceeding. (Note case of Chief Gunner's Mate Hill, late of the *Dubuque*, who met his death by drowning while diving with helmet alone.) When using the helmet alone the air escapes just below the breast plate. This tends to obstruct the view through the face plate and prevents stooping over, owing to the inrush of water about the face. If the jacket was used the air would escape below the body line, and would afford the diver a greater bending angle, and would also eliminate the inconvenience caused by the water entering the helmet.

10. *Buzzer signals.*—An electrical push button attached to the breast plate, with shield guard for protection against obstructions, but with opening on side for easy access of finger for operation. When diver is being lowered and strain is on line it is

impossible for him to return signal on account of tautness of line, in case communication with tender was necessary on account of feeling of nausea, bleeding of nose, choking, or other illness.

11. The writer is of the opininon that the above suggestions, if put into practical working form, may lead to some definite improvement on diving and the diving outfit in general.

C. H. Foster.

U. S. S. "Montana,"
At sea, April 27, 1914.

My Dear Stillson: In answer to your letter relative to diving operations:

(*a*) None.

(*b*) More care should be given to outfits issued to the service. They should be used more frequently than they are. Regular diving ladders for use in boats should be issued with each outfit.

(*c*) The outfit manufactured by the Andrew J. Morse & Sons seems good to me. Boat should be rigged properly, suitable floor room in bottom of boat for pump and men manning pump.

(*d*) I allow a rest of one minute for every ten feet in descent and coming up, lowering, and bringing up slowly.

(*e*) Man came up almost unconscious, due to rush of blood to the head; had been head down too long while trying to make a line fast to object buried in the mud. Inlet valve stem broke off in one cylinder of pump, but other cylinder did the work, and the man never knew the difference until told so when he was brought up.

(*f*) One hundred and fifty feet.

(*g*) This I could only tell by experiment.

(*h*) Horse sense exercised by the one in charge of the operations.

(*i*) Andrew J. Morse & Sons.

(*j*) Pick men who are physically qualified and who are cool and collected; fit up a boat with apparatus the same as would be used in the service. Use the same kind of boat. It is a mistake to have a special boat at a school the like of which can not be found on any ship in the service or any special type of apparatus which are not the ones they will use in the future. Pensacola Bay would make an ideal place for such a school, as work could be carried on the whole year. Try out in shallow water and gradually work into deeper water. Three months instruction is not too long.

I have found a large number of men who have on their record qualified as divers that are practically useless as divers.

A motor sailing launch fitted with a canopy to protect men from the weather.

Floor installed forward of motor bulkhead for pump and pump men.

Full outfit in boat: Pump and 2 chests; at least four oars; large tackle; 2 small tackles; 1 line and grapnel; 4 lines with mushroom anchors, 50 pounds each; heavy bow and stern painter, 3 inches; 1 good, long 4-inch line about 20 fathoms, with 6 feet of ⅝-inch chain and shackle; thole pins and grommets; 4 different sizes of selvagee straps; 4 different sizes of tail straps; 4 different sizes of ordinary straps; 1 red flag and staff; anchor and plenty of chain, bow and stern roller; boat box fully equipped; 2 marker buoys, cork, 18 by 12 inches (about); compass; signal flags, wig-wag and semaphore; clock; 8 fenders; 3 boat hooks; wooden props for drying suits on; rope yarns; bucket of sand; gasoline fire extinguisher.

One 14-foot wherry for tender, row locks, rudder, tiller, oars, painter, stern post, fenders, marker buoy line and 50-pound mushroom anchor.

Men should be taught how to work under water, slinging heavy weights, which should be brought to the surface and landed. They can not get too much of this experience.

Have a dummy torpedo which will sink, having a stop valve and propellers; men should be taught how to drop marker buoy over it. It should have a compartment that could be charged with that which would give off bubbles, so it could be located and marker buoy dropped over the spot. Diver should go down, close stop valve, put on propeller lock, and sling torpedo properly for hauling up.

Two divers should be sent down at the same time every day, and work together under water for at least an hour. In my 25 years' experience I have never seen two divers down at the same time.

Too much stress can not be laid on the fact that only such gear should be used at the school as will be found in the service, or can be readily made up from material at hand on board ship.

All men at the school should have setting-up drill twice a day. They should be taught to dive under a ship's bottom, to locate the openings, etc., how to rig lines under a ship's bottom. Divers in the service do not get enough experience.

(*k*) The pay should remain the same as it is now.

For articles of value such as torpedoes, anchors, and chain, or articles lost overboard, the commanding officer should offer an inducement for the diver to get the article as soon as possible—say $5 to the diver who puts the line on the torpedo that brings it to the surface, the amount of money to be determined according to the value of the article.

(1) Eight hours for 20 feet or less when water is not too cold. Fours hours for 20 to 60 feet when water is not too cold. Two hours for 60 to 90 feet when water is not too cold. One hour with a two hours rest between for 90 feet or over.

Climatic conditions make very little difference to the diver while under water, as artificial means can be used for cooling air, such as ice in reservoir around pump cylinders. The men on top are the ones to feel the heat or cold, especially the tenders.

(*m*) A steam launch should be fitted with a pump capable of delivering a 2-inch stream of water at 80 to 100 pounds pressure for use in connection with diving operations. A hose of sufficient length to reach the diver so he can wash out an object buried in the mud of the bottom.

A small compass contained in two glass hemispheres, hermetically sealed and fitted with a handle, could be used as a guide under water, to be fastened to the belt.

I once used a boat compass hung around a man's neck, and he had no difficulty in following a straight line with it and turning through any number of points signaled and going in that direction.

This is about all I know on the subject.

We arrive at Vera Cruz, Mexico, to-morrow.

HERBET CAMPBELL.

UNITED STATES NAVAL TRAINING STATION,
Great Lakes, Ill., April 28, 1914.

From: Chief Gunner C. J. Miller, United States Navy.
To: Gunner G. D. Stillson, United States Navy.
Subject: Submarine armor, diving apparatus, appliance, diving operations, etc.

In reply to your semiofficial letter, I will make the following reply, hoping same will be of help to you in perfecting what is urgently needed, a trained corps of submarine divers.

In answering your questions I will strictly adhere to your subject, and relate a few anecdotes of my personal experiences while conducting diving apparatus aboard ships in a separate sheet.

(*a*) Suggestions for improvements in construction of diving apparatus:

The present diving apparatus can be improved upon by placing large casters on bottom of pump, such as are used on safes, to wheel same about from place to place on shipboard. The casters should be arranged so that they may be unshipped when actual diving begins, so pump can be properly secured.

(2) The lid of the pump so fastened that when in use same can be unshipped, as at present same occasionally falls down, and in that way is a hindrance (supposing, of course, that lid is up when pump is in use). I always insist on this, so I can watch the action of my pistons and valves.

(3) Two eyebolts should be permanently secured in a boat which is habitually to be used for diving, to secure the pump to by means of turnbuckles, which should be furnished with pump. Heretofore we usually lashed same, which takes time and is a hindrance otherwise.

(4) The hemlet should be secured to the breastplate with a bayonet joint in place of the screws used, in which case a small heaver can be inserted in the face plate hole and secured.

(5) The tool tray in pump should be placed in some other place, as occasionally one wants to get a tool and another falls between the pistons, which might cause a serious accident.

(6) The belt is entirely too heavy. The design should be changed, and in place two heart-shaped weights should be used—one on breast and one on back. A light set for shallow diving and one heavier for deep-sea diving.

(*b*) Suggestions for improvements in method of constructing diving operations:

(1) The following suggestions are submitted on the above questions based on actual work. To begin with, a diving party should be a permanent corps, regardless of and in addition to their other duties; be so trained in their duties and qualified so that when an emergency arises and a diving party is called away same is to equip launch, or other boat detailed, in an expedient manner and in a way as "man overboard." The party shall consist of the following personnel: A chief gunner, gunner or chief gunner's mate in charge, 3 divers, 4 pump men, 4 boat crew, and a coxswain, in all 12 men, an ample number when the power boat is used. If another boat is used, she is usually towed, and in that case the above crew is sufficient. The pump men to be trained in dressing divers, and given an opportunity occasionally to take a dip if they so choose to qualify themselves as divers in the future.

(2) Suggest that diving be carried on more frequently than occasion demands, say weekly, a diving party be sent away and a forenoon or an afternoon be devoted in giving actual diving experience under adverse conditions, such as weather, depth, bottoms, etc.

(*c*) Criticisms of present types of diving apparatus and various methods of diving:

(1) The present type of diving apparatus in the naval service, I find with minor improvements, as suggested in previous paragraphs, adequate to the naval demand. I would suggest that the telephone be done away with, as it has proven a failure, as the chuck, chuck of the pump deadens the sound wave, and in addition makes it dangerous for the diver in fouling. Not in use by commercial diving concerns.

(2) By the various methods of diving I would prefer suit or helmet diving. The former where the water is deep, cold, and infested with sharks; the latter in shallow water, the Tropics, and where the water is warm and clear. Although I have conducted helmet diving in 60 feet of water off Tangier Sound with great success. One must be a good diver, have a lot of confidence in his own ability to make a success of helmet diving. It naturally assists in this case, as one is not hindered with suit, weights, shoes, etc.; staying down at short intervals, making a thorough survey of the bottoms for the lost article, and when satisfied, comes up and makes a report on same. Diving launch is shifted; in that way one can cover more ground in a given time, and the diver is not fatigued as much, and as a whole has a decided advantage for expedient work over the suit diving.

(*d*) Description of important diving operations; including that of apparatus; divers; method of diving; times of descent; remaining under water; and ascent; effects on divers; depths reached; and general remarks, etc.

(1) The most important diving operations in which I took part, occurred some years ago when on board the *Cleveland* in Cienfuegos, Cuba. It appeared that we had run aground some months previous but the exact extent of the damage was not apparent as we had no divers on board. I informed the gunner's mates that I wanted some one to do the diving and it was up to them to volunteer, two first-class gunner's mates volunteered. I rigged the diving gear on the forecastle, placed hogging lines under the ship's keel to which I secured oars, longitudinally, and gave my men the preliminary instruction regarding measurements, from frames forward, etc.; as she was composite, found later that the copper was rolled off the keel to an extent of 50 feet. My man went down at 8 a. m., and at messgear (11.45), he was still at it; I thought he had done enough, so I hauled him up. His first remark was "Why did you haul me up; I only had to measure a few more feet?" He completed the job that afternoon, and I made a sketch from his figures and gave them to the commanding officer, and months later when we went in dry dock those measurements were accurate enough for the most skeptical. I merely mention this to show what can be done with men who get the right instructions. I personally qualified those gunner's mates, who were not graduates of the seamen gunner's school, and I was informed later that one of these men was of great assistance to Gunner Simonski, when he had occasion to raise the dry dock *Dewey*.

(2) The greatest depth any diver worked for me was 130 feet; the pressure at that depth was such that had he not been used to about three weeks' previous diving at 90 feet, he could not have stood it. I consider that very good diving for a naval man, although I know that greater depth diving is going on daily with the various wrecking concerns. Deep-sea diving, say 150 or 200 feet (the latter which is the record), is not acquired by just putting on a suit and sinking to that depth, but, by constant practice, increasing the depth, as one becomes accustomed to the new surroundings and pressure. A man can stay under water (depending upon the depth and constitution of the individual) for hours at a time. I have had a man working with pick and shovel at 60 feet, stay under one hour and a half, and then I gave him a spell of 10 minutes, and he finished the job in another half hour. I noticed that after a day's work with two divers alternating, each diving about three hours, the only effect felt was drowsiness and a tendency to go to sleep—outside of that no ill effects appeared.

(*f*) What is considered the maximum depth at which divers can perform useful work under water?

(1) From my experience the greatest depth that our divers can perform useful work is about 120 feet.

(*g*) How may the apparatus be adapted for use at greater depths?

(1) The most essential part of our apparatus is the pump, as that has to deliver a certain amount of air per foot depth increasing as one descends—the fundamental principle would be to see your pump is capable of said output. I notice that adverse criticism has been passed on the pump in use in the service. I always found it reliable, in fact to such an extent at times, that I could hardly control the minimum amount of air, or the diver would signal for less air, at a depth of 60 feet. This no doubt due to the care the pump received, all leakage stopped, packing renewed occasionally and pump lubricated. Even when standing the packing becomes dry, cracks, and the springs lose their tension; to avoid the latter, when pump is stowed, always see that tension is off all valve springs, that packing is kept moist, that valves and rods are well lubricated and that pump is turned over periodically. See that intake valves are protected so no foreign substance can accumulate. If these in-

structions are followed I am sure the outfit, as furnished, is good enough for any depth the average naval diver desires to go down.

(*h*) What precautions should be observed to protect divers from dangers to which the nature of their work subjects them?

(1) The above question will involve diving in open water free from obstruction and in water strewed with wrecks and wreckage. The former can be answered by seeing the pump is in working order, all hose connections air-tight, the intake and exhaust valve on helmet are properly adjusted, and last, but not least, your signals with the diver are rehearsed and thoroughly understood before the face plate is put on.

In very deep water also see that a descending line is used; in lowering always make sure that you have the weight of the diver; this is to insure that he is not being lowered too fast and receives the deeper water pressures gradually, and when he reaches the bottom always insist on the "I am on the bottom and everything is O. K." signal. Then at an interval of a few minutes repeat the same signal, if the latter is followed up, should you fail to receive an answer, you will then have ample time, provided he is not fouled, to pull him up and revive an apparently asphyxiated man.

(2) In protecting and safeguarding a diver in working, always see that his hose and life line is clear and watch carefully the air bubbles so you can judge by them his whereabouts. A good deal depends on the man handling a diver, and the diver's success depends to a great extent on the person tending him. In addition to the above, wish to say that a tender who knows his business will materially assist the diver and lighten his work in a good many ways; for instance, if he sees that the diver is heading the wrong direction, pull him in with the life line until within the the starting point and direct him with the aid of the life line on his new course. In shark-infested waters be constantly on the alert for the sea monsters, and have your diver under control in case of any emergency so you can haul him up out of harm's way.

(*i*) What do you consider the most efficient form or type of diving apparatus?

(1) Our diving apparatus compares very favorably with any of American output in use by the various wrecking companies. When one considers a good many use nothing more than a handy-billy for the pump, it is apparent that ours far excels.

(*j*) How would you organize a school of instruction for divers? How would you proceed with the instruction of candidates for the course in diving?

(1) To begin with, if you have your choice, select from the various candidates young, strong, and robust men with no physical defects, who possess an even temperament—one who shows no intimidation or weakness. Their size to be taken into consideration, not over 5 feet 10 inches and under 5 feet 6 inches; must not have a venereal disease nor overindulgence in intoxicants. In selecting, it would not be necessary to conform to certain ratings, as better material can often be found among others. I once had a coal passer who I would put against any postgraduate navy diver. After you have made your selection, say, about 30 men, should by constant work around New York waters qualify in about two months; then distribute them through the fleet and then take up another class.

(2) In making preparation, outfit a sailing launch with an engine so you could work independent, have the entire outfit that would be used on shipboard (nothing different, as it would only be confusing when they get on shipboard) and take them out daily, beginning with, say, a depth of 20 feet and working through the various depths to 120 feet. After they have individually demonstrated that they can dress and handle a diver and make minor repairs to the outfit, etc., I would qualify them as divers with an additional compensation of $1 per month. You probably notice I say nothing of tank diving like the English conduct their class. I do not approve of the above method, as it is so different from the real thing that once they qualify from such artificial diving they are either no good for real work or will have to start all over when they attempt to go down on the ocean bed.

(*k*) What are your suggestions in regard to the pay of divers?

(1) I would say I regard the compensation of $1 per month as sufficient in plain diving. When an anchor or a torpedo is lost and same is recovered by ship's diver, a sufficient sum should be paid him to compensate for his service in addition to the $1 per hour he receives while diving for same.

As the Secretary of the Navy has offered $500 for the recovery of an anchor, I do not deem $25 exorbitant for such recovery. This would give the divers a new lease on life and all would want to become more proficient in their calling.

(*l*) What constitutes a day's diving work under various conditions of climate, location of operation, state of weather, of work, etc.

(1) In reply to the above I can say from authentic source that divers receive different pay for different kinds of diving in civil pursuits. Those that came under my observation were required to work six hours a day under the depth of water 10 feet, they receiving for this work $10 a day, but when this same man worked in deep water—as is generally required of the naval man—he received $25 per day for six hours. When salving, of course, he generally worked on a commission. Being personally acquainted with men who work for diving concerns in civil life, I gleaned the above information from time to time.

As all the alphabet has been answered to the best of my experience and ability, I will proceed with a little narrative that happened while I was attached to the *Nebraska* last August. We were at torpedo practice in Guacanagabo Bay, Cuba, and were having unusually hard luck with torpedoes. They all seemed to run, but kept on going once they started—this one in particular sank in 120 feet of water. I was right on the spot with diving-gear men dressed and down to work. After I sent a man down to survey, he came up on his own accord and informed me that the torpedo was on its way to h—— (the mud being very soft), and said that he could only see the tail and that the propellers were still turning over. I immediately signaled launch to procure a shovel, and fortified with that I sent my man down after the torpedo. He worked for over an hour, and when I hauled him up rather exhausted from his strenuous work he informed me that he dug a hole 20 feet deep and the torpedo was still under way. I sent a relief diver down, and he was down another half hour when he signaled for a line. I sent down, heavily weighted, a 5-inch line, which I had previously sent for by another launch, and with this he made fast to the tail of the torpedo. He then came up and informed me that he put a timber hitch on her, as he could only get one turn. I told him that was enough. We shipped windlass and funnel and went to work, and believe me we hove the launch down to 1 inch freeboard, but no go. In the meantime the ship was maneuvering close by, and at the suggestion of the officer of the deck we passed the hawser to the ship; same was run through her hawse pipe and a turn taken around the winch. The first few turns straightened the line out taut to such an extent that the ship's head was swinging around by the tension. Another few turns and the torpedo shot out of the water a distance of 10 feet, so great was the strain on line. You can gather from the above narrative the distance this torpedo was in the mud of Guacanagabo Bay.

Having come to the end of my narrative, I hope some of the inclosed suggestions are practical enough to be of assistance to you in your undertaking, and I wish you luck and success.

I remain, yours in service,

C. J. Miller,
Chief Gunner, United States Navy.

P. S.—Am in the hospital at the above place. Have a bad attack of rheumatism The climate don't agree with me.

U. S. S. "SOUTH CAROLINA,'
Vera Cruz, Mexico, May 17, 1914.

DEAR STILLSON: What I don't know about diving would fill a large book. That is to say my diving days are gone so long ago and I simply observed the rules and instructions that were contained in the little pamphlet that usually accompanied the diving outfits.

I would suggest that you write to Andy Olson (chief gunner). As far as I can remember he has had more real experience in diving than anyone in the service.

I am sorry that I can not furnish you with some dope too.

I am yours, truly,

O. BORGESON.

U. S. NAVAL MAGAZINES AND CHEMICAL LABORATORY,
Philippine Islands, Olongapo, May 18, 1914.

From: Chief Gunner John T. Swift, United States Navy.
To: Gunner G. D. Stillson, United States Navy.
Subject: Submarine armor, diving apparatus, appliances, diving operations, etc.

1. Your letter relative to the above subjects received last mail, and was pleased to know that such extensive tests and experiments were being carried on to increase the efficiency of this important work.

2. From my own limited experience as a diver and tender I am afraid I shall fall short in giving you any information outside of what you already know, that may be of value. In regards to the tabular list submitted in your letter, I will proceed as follows:

(*a*) Helmet or breast plate to be fitted with 3 or 4 eye bolts to allow of the helmet being swung when diving without the dress (as divers frequently work in shoal water and moderate depths). Life line to be water-laid rope. The diving weights to be fitted so as to be more flexible than at present, I mean so that the weights can be taken off or put on readily. This would be of great help when diving around propellers or under ships bottom, or in shoal water. All washers to be of porpoise hide.

(*b*) Divers should be taught to go down in shoal water without the suit, only using the helmet and breastplate. When using a launch a platform should be fitted to overhang the stern so that the tenders could better assist the diver to get on the ladder when ascending. This is generally very difficult, especially when the diver is tired and can't assist himself as he should. Greater discipline should be maintained with the working parties during diving operations. Seamen only should be detailed for the working parties for the rigging of stages, getting hogging lines around, and the numerous jobs that are constantly coming up whenever diving is being carried on.

(*c*) The only criticisms of the present diving apparatus that I can make is the poor washers that I have found in diving apparatus and the life lines which are ordinary manila rope. The life line should be water laid, which no doubt would be found more serviceable for this class of work. I believe all helmets should be fitted with four lights, one light being above the front light to enable the diver to look upwards without throwing the body back; this is, of course, fitted to some helmets now.

(*d*) Personally I have always used the regular diving outfit supplied to the Navy, with and without the dress. The time of descent I generally control when I have charge of diving work, by lowering the diver with the life line. I also generally have a descending line, by which the diver helps himself; this no doubt is the general way this is done throughout the service. As to remaining under water this must be up to the diver himself without you want to bring him up, and it also depends on the depth, and the same may be said of ascending. Both in descending and ascending the diver should be handled slowly and carefully and in ascending when fully dressed the pump should be carefully watched and not worked too fast, so as to inflate the suit to help the diver up. I personally have been turned upsidedown a couple of times while ascending due to the pump being used to inflate the suit, as they said, to help me up. The effects of diving I think must be the same to the average diver, the ears plugging up, nose bleeding, general nervousness when first going down and signalling for extra air, etc. The remedies for the above are too well known to be given here.

(*e*) I had an accident while on the *Rhode Island* which may be worthy of note here, although I am glad to say it did not turn out to be a serious one. I had a diver down in about 95 feet in Manila Bay searching for a lost torpedo; he was continually signalling for more air and the pump was working very hard; finally I pulled the diver up and undressed him and examined all parts of the outfit and found a partly spread and broken washer in the inlet valve which was not allowing the full amount of air to the diver. The washer was of common leather, and I think if it had been a porpoise hide one it would not have broken as it did.

(*f*) I personally should say that 100 feet is the maximum depth at which divers can perform useful work.

(*g*) I can not suggest anything in this line. It seems to me that the present apparatus meets all requirements as to depth.

(*h*) When divers are called upon to go down I believe that only seamen should be allowed to assist in manning the pump, rigging stages, hogging lines, etc. The attendants should all be divers themselves, so as to be familiar with the work in hand and better able to assist the diver and realize the necessity for extreme caution and alertness when the diver is submerged and at work. Silence should be allowed in the boat. Whenever the diver is partly dressed care should be taken that the bitter end of his life line is made fast securely, and the diver should not be allowed to rise until this is accomplished. Soundings should always be taken before the diver goes to bottom. The crinoline should always be used for greater depths than 75 feet. All signals should be understood between diver and attendant before he is allowed to go down. All attendants should know how to manage a person apparently drowned or in an unconscious condition.

(*i*) The present outfit supplied to our vessels seems to meet all necessary requirements for deep diving, but for diving under ship's bottom or at work on openings in the under body of ship or propellers and when temperature will allow it I am in favor of only using the helmet and breastplate with pump.

(*j*) I believe a school for the instruction of divers should be an adjunct to the gunnery school as at present but with a greater scope than it enjoys at the present time. All men in gunnery school found physically fit and willing should receive instruction.

I would suggest a large tank with a depth of at least 30 feet and diameter sufficient to give all men receiving diving instruction their elementary training work to familiarize themselves in dressing, tending, manning pumps, signals, and preliminary diving, etc., the tank to be fitted with lights of heavy plate glass by which the operations of the diver could be observed from the outside of the tank. All men should understand taking the pump apart and reassembling the same. Also the nomenclature of all parts, its care, and preservation; how to prepare the outfit for use preliminary to the diver going down, its care while in operation, and its care when work is finished, and before it is stowed away; how to rig launch, sling pump, etc., over side.

They should know how to dress the diver and care for him, examination of gaskets, springs, etc., and the proper name of all parts, and care of the outfit before being stowed away, and its repair. They should know how to search for lost articles, the manner of walking on the bottom with and against the current, how to send a line down to the diver when he signals for one, how to approach a lost torpedo, and what to do in case it is partly charged, etc.

Two divers down together and how to look out for them, arrange pumps, etc.: fitting stages, getting hogging lines over, etc.; communication with slates and telephone between diver and tender.

Going down fully dressed and partly dressed (helmet and breastplate used only).

Instruction in bringing to the apparently drowned from the unconscious state.

Instruction in repairing leaks in the under body of vessels, coppering so as to acquire the use of the hammer, at work with electric lights, etc.

After the tank work the diver should be instructed in deep water diving to at least 100 feet before he qualifies.

A diver who has passed his examinations successfully should receive a special certificate giving him the status of a qualified diver which he should be in every respect and for which he should receive at least $5 per month extra, same as gun pointer, etc. If at any time he should fail to go down when called upon (except when sick or under unusual conditions), his certificate should be revoked and the extra compensation stopped. I am of the opinion that a qualified diver should wear a device of some appropriate design which the wearer no doubt would be proud of and which would make this hazardous work more popular with the service.

(*k*) In regards to pay for qualified divers, as I have said before, they should be allowed a monthly extra compensation; the pay should also be rearranged. I am of the opinion that the pay $1.20 per hour as at present be allowed to a depth of 50 feet; but that a breathing spell of 15 minutes should be allowed for every hour. When working over a depth of 50 feet, the pay should increase every 25 or 20 feet. Also special pay should be given for hazardous work or when the results of a diving operation means a great financial benefit to the Government such as recovering anchors, torpedoes, mines, etc.

(*l*) A day's work must be up to the diver, if the necessity demand it work should be carried on from early morn to late at night, diver being relieved as found necessary. Every minute the diver is at work means pay to him. A diver should enjoy the right not to go down if he feels that his life is endangered thereby or that he is physically unfit at the time.

(*m*) I think that more thought might be given to fitting out the diving launch. A portable extra platform should extend out over the stern to enable the tenders to get out past the ladder so that they can assist the diver to get on the ladder with less effort on his own part when ascending, this platform to be fitted so as to be easily attached to the launch and to be part of the diving outfit; eyebolts should be fitted in all sailing launches for securing the pumps, and diving ladders, iron, should be part of the outfit.

If a school for divers should be established, I am of the opinion that the tank which I suggest will be found very useful for instructing divers in preliminary training work, whatever orders the instructor gives to the diver can be observed and he will know if the diver carries them out, it would give more confidence to the men when going down dressed and partly dressed, would be just the thing for winter's work, when no doubt it would be most used. I remember when I first went down off the Torpedo Station dock and went up to my middle in mud in about 20 feet of water; I could not budge; you can imagine how much work I done.

This completes the information I can give you on this very important subject, of which no doubt you will find a great deal which is old and superfluous, but from which you might possibly find something that may be of service to you.

Trusting it may be of some use to you in making up your report, I remain,

Very sincerely yours,

J. T. SWIFT.

U. S. S. "TEXAS," *Lobos Island, Mexico, June 4, 1914.*

From: Chief Gunner, A. S. Pearson, United States Navy.
To: Gunner G. D. Stillson, United States Navy.
Subject: Submarine diving.

1. In reply to your letter from the experimental diving station, Brooklyn, N. Y., and the queries therein, the following is submitted.

(*a*) Suggestions for improvement in construction of diving apparatus:

I have found the diving outfits issued to the service adequate, for such diving operations as I have been called upon to supervise.

(*b*) Suggestions for improvements in methods of conducting diving operations:

No suggestions.

(*c*) Criticisms of present type of diving apparatus and various methods of diving:

See answers to queries (*a*) and (*b*). The telephone as installed is useless. This can be made useful by providing a headpiece for diver. This headpiece containing a receiver similar to appliance used by telephone operators.

(*d*) Description of important diving operations, including that of apparatus, divers, method of diving, times of descent, remaining under water, and ascent, effects on diver, depths reached, and general remarks, etc.:

My experience with divers could hardly be considered as important; during a three years cruise on a torpedo experimental ship I had charge of diving parties recovering sunken torpedoes. In all about 80 diving operations were performed, but in no case in a greater depth than 40 feet. In recovering torpedoes it requires a certain amount of grit and perserverence on the part of the diver in working a way through mud. Frequently a tackle was used to break the diver out of the mud. The divers state that other than the pain inflicted under the arms, chest, and back due to the strain on life line in being broken out of mud, no bad effects were noted.

I make it a rule to let the diver descend himself on a descending line. The life line well tended to guard against the diver falling to the bottom. In ascending the diver is hauled up slowly.

(*e*) Detailed description of all accidents to men or apparatus:

A diver was down on bottom in 30 feet of water and his faceplate flew off. The diver gave signal to come up, and much to everyone's surprise and at his own request another faceplate was screwed on, he descended, and successfully dug out and recovered a sunken torpedo. The diver was wet, but not more than a quart of water came in through faceplate aperture. This accident was due to using a Schrader faceplate on a Morse helmet.

In recovering a Mark V torpedo which failed to start and sank in 30 feet of water, a diver was fastening a light line around the propellers. The engines started. The torpedo came up and went 20 feet out of the water within 3 feet of the diving launch, then down again tail first, came up clear of the water again, fell over, and continued a fairly straight course down torpedo range. Fortunately the diver's hose and life line were not cut by the torpedo's propellers. The diver lost two fingers and his hand was otherwise cut up. It was noted that there was not any great flow of blood until the cuffs and snappers around diver's wrist were removed.

(*f*) What is considered the maximum depth at which divers can perform useful work under water?

I would not care to assume responsibility for sending a diver down to a greater depth than 100 feet unless to save life. I have never had occasion to send a diver down more than 60 feet.

(*g*) How may the apparatus be adapted for use at greater depths?

See answer to above (query (*f*)). An increased pressure may be obtained with comfort to the diver by connecting two pumps to supply air to one diver.

(*h*) What precautions should be taken to protect divers from the dangers to which the nature of their work subjects them?

Keeping in view the almost helpless condition of the diver, every known precaution should be taken.

(*i*) Which do you consider the most efficient form of diving apparatus?

I have had experience with the Morse and Schrader diving apparatus supplied to the service. I have found them both efficient and adequate for such diving operations as have come under my supervision. I have no preference.

(*j*) How would you organize a school of instruction for divers? How would you proceed with the instructions of candidates for the course in diving?

The diving class should be under the direction of a chief or gunner of well-known practical experience as a diver. There should be a chief or boatswain to supervise the practical instruction of seamanship to cover especially rigging for lifting and transporting heavy weights. A chief or machinist or carpenter to supervise handling machine tools and practical ship construction, drilling, tapping, calking, riveting, and ship fitting, including woodworking instruction. The diving class should not be confined to gunners' mates nor to the seaman branch. Any good man who shows marked initiative should be permitted to receive a course of instruction in diving. Men of the artificer branch, shipwrights, carpenters' mates, shipfitters, blacksmiths, machinists' mates, and boilermakers would be especially desirable candidates. The class should be composed of active, physically strong, resourceful men; men recommended for showing extraordinary initiative. A man to be a useful diver should have all the above qualifications and be what is commonly termed as a "good all-round man."

The class should first receive practical instruction in rigging for and transporting heavy and odd-shaped weights. Those who show no ability or only medium ability in this work and in practical seamanship should be dropped and disqualified.

The exceptionally good men, after passing a rigid practical examination in the above portion of the course, should then be given practical diving instruction. After men have had diving experience they should be given practical mechanical instruction, especially ship construction, including drilling, tapping, calking, riveting, and ship fitting, and in addition show ability with woodworking tools. A course in steam engineering machines and machine tools would be of much importance.

Above all, a man to be a useful diver should be one that at least above water could, for instance, sling for lifting a boiler in tight quarters; put a sling around a gun with some assurance of his sling holding and the gun swinging nearly level. It is with regret that I am compelled to state that the qualified divers at present, with few exceptions, are lacking in practical ability to give even any kind of good service under water. It is surprising the number of men with records as qualified divers who can not be relied upon to render service even in a minor diving operation, due to their lack of knowledge of practical seamanship. To sum up, a man's ability to dive is of absolutely no importance unless he has the ability to do things under the water.

All men at present with records as qualified divers should be reinstructed, and those not coming up to a high standard of efficiency should be disqualified.

(*k*) What are your suggestions in regard to pay of divers?

Give qualified divers $5 per month in addition to their pay; qualified divers to prove their qualifications at least once each year. See answer to query (*j*) for qualifications of divers. Qualified divers should be ready for a call at any time, all responsibility to be assumed by the officer ordering the diving. A refusal to dive, unless excused by the doctor, should disqualify a diver, and in certain cases the diver should receive such other punishment as may be awarded for refusing duty or disobedience of orders.

(*l*) What constitutes a day's diving work under various conditions of climate, location of operations, state of weather, depth of submergence, nature of work, etc.?

This depends upon the endurance of the diver.

A summary of the most interesting points brought out by your correspondence will be of great use to the service, and a copy for my own use would be much appreciated.

A. S. PEARSON.

U. S. S. "MOHICAN,"
Cavite, P. I., June 5, 1914.

From: Chief Gunner J. Mitchell, United States Navy.

To: Chief Gunner G. D. Stillson, United States Navy.

Subject: Submarine armor, diving apparatus and appliances, diving operation, etc.

1. I have no comments or suggestions to make.

J. MITCHELL.

U. S. S. "TALLAHASSEE,"
Chiriqui Lagoon, Panama, June 6, 1914.

MY DEAR STILLSON: Your letter relative to diving received some time ago, but I have been sick and did not feel able to get down to answer it. I will try to explain the weak points in diving as I see them.

1. The system now in vogue, i. e., that of instruction to enlisted men at Washington, D. C., is poor, from my own observation while on duty at Indian Head. I find that the work under a chief petty officer is blurred over, and the Potomac River a very poor place, always muddy. Now, you know that diving is a thing that all men who can pass the doctor are able to take up, but in my experience I have found few who can really locate themselves when under water, notwithstanding the instructions you always give them to look up and find how life line and hose lead, bearing of same, if possible to see the gleam of same, shadow of diving boat, tide elements, all of which comes to men when in practice, but this practice never or seldom comes to the enlisted men.

2. (*a*) *Helmet.*—This is looked upon by Navy divers as a covering for head, while the fine points of the game are not known; for instance, the check valve in the gooseneck from helmet to diving hose is not inspected and cleaned. Result, sticking open or shut, probably open all the time, and if pump is stopped air from suit exhausts back to pump, which is a bad thing if it becomes necessary for diver to live on air contained in suit until pulled up. (*b*) A button valve is fitted in helmet which can be pressed in by back of diver's head, shutting off exhaust from helmet should it become necessary. I have found a deplorable lack of knowledge of this.

3. (*a*) *Breastplate.*—Probably of good design, but few seaman gunners know how to put rubber of suit over studs of breastplate. Result, torn rubbers and the suit needing repairs when in other respects new. (*b*) Poor manner of stopping life line and hose to studs on breastplate. I think for the hose a circular clamp would be best.

4. (*a*) *Suits.*—Any size seems to be used irrespective of the size of the diver. This fault is only bad when the diver is small and, unless overalls are pulled well up, the man's head is low in the helmet, and faceplates or side plates so that he can not see properly. (*b*) Arms of suits when under water are usually so inflated with air that diver can not reach his relief valve should he find it necessary to adjust, and instructors probably never instruct men that this can usually be accomplished by sticking a finger under wristlets to allow air to escape.

5. (*a*) Breast weights are not fashioned so the excess weights can be conveniently taken off. Result, divers carry full belt at 20 or 100 feet when they could do work

better at 20 feet with half a belt of weights. (*b*) Buckles on life belt should be of such a design that diver could take belt off without trouble should it become necessary.

6. (*a*) Crinolines should always be used, I would say, when the depth of water was 80 feet or over. Seldom, if ever, used in the service. Result, men with weak abdomen muscles feel the pressure doing work, and in some cases have been unable to breathe properly at 100 feet.

7. (*a*) Hose seems of good design. I have never seen any trouble with it, unless by carelessness.

8. (*a*) *Life line.*—This, I think, should be of the best material, water-laid, and not, as we usually find in service, plain 21 or 24 thread manila. I also find that seamen gunners are very careless about the knot taking in the eye of the splice, so that should there be any extra strain on life line and the stop breaks life line is pulled until diver is almost cut in two before he is gotten up. Usually poor instructions.

9. (*a*) Shoes probably of good design, but through carelessness in dressing have known diver to lose a shoe in places where the bottom is muddy.

10. (*a*) *Pump.*—This is a machine that few seamen gunners know thoroughly, and, while almost foolproof, we sometimes have trouble through carelessness. One point is sure, that in diving in the Tropics there is never any attempt to keep cylinders cool, and thereby cool the air to diver; but I find that instead of using the standard pump divers use the air from the torpedo compressor tanks of the submarine boats with a reducing valve. This, in my opinion, is a very dangerous substitute for the standard pump. We know that should a relief valve stick shut in the helmet the pressure on the pump gauges will go up and the pump work correspondingly hard; this tells us something is wrong, but with the tanks a great pressure may be shot down to diver for an instant; no one notices it and the man is killed.

11. (*a*) Knife seems poor to me with a screw thread, whereas some simple device could be rigged which would allow a diver to get it clear in an instant.

12. *Wristlets.*—Rubber is of all thicknesses; should be fairly thin.

13. Hoping you may find some information in this—but I am afraid not, for it is what every diver knows—I remain,

Sincerely, yours,

W. G. Smith.

United States Naval Station,
Olongapo, P. I., June 18, 1914.

From: Chief Gunner H. A. Nevins, United States Navy, assistant engineer officer Olongapo, P. I.

To: Gunner G. D. Stillson, United States Navy, experimental diving station, United States Navy, 783 Atlantic Avenue, Brooklyn, N. Y.

Subject: Submarine armor, diving apparatus, appliances, diving operations, etc.

1. In compliance with your letter I offer for your consideration the following suggestions:

(*a*) Light type of pump with short hose. Better and lighter weights should be gotten for ordinary work on ships' bottoms, propellers, or clearing strainers.

(*b*) Would suggest that diving apparatus and operations be divided into shallow water and deep-water operations.

(*c*) The telephone as installed in diving apparatus is, to my mind, absolutely useless and the transmitter and receiver in the helmet are detrimental to the work of the diver. Telephones of present type are widely open to criticism and should not be installed in a diver's helmet. The type of helmet which locks with a bayonet joint is, to my mind, far superior to the type locking with four bolts.

(*d*) Since I have been here in Olongapo a small tug was salved in about 80 feet of water. The Filipino divers are accustomed to working with a helmet only. One American negro when diving followed this practice, was caught and drowned. Unfortunately, not having been an eyewitness to this accident, I can not give a detailed description of it.

(*f*) I have no knowledge of the maximum depth at which divers can perform useful work under water, as the deepest I have ever been is 90 feet, suffering no ill results at that depth.

(*g*) Have seen descriptions of water-tight armor with hinged water-tight joints for working in water at great depth. Would imagine that apparatus of this sort properly worked out would be preferable to rubber armor and any type of crinoline.

(*h*) Intelligent supervision of the work of diving and obedience to the officer or person in charge of diving are the best precautions which can be taken.

(*i*) I consider the Morse outfit with 2-cylinder double-acting pump the most efficient commercial type of diving apparatus.

(*j*) No remarks.

(*k*) Pay of divers should start from the time the order is given to get diving apparatus up and continue during the total time diving operations are continued. That is to say, that dressing and undressing a diver are as hard on the diver as the actual work performed under water and for this reason the time of the diver should count during the dressing and undressing operations and not be taken from face plate to face plate.

(*l*) Under very favorable conditions a diver of strong constitution can perform approximately eight hours' labor a day. Under less favorable conditions the time would be shortened and this time would be governed principally by the constitution and capabilities of the diver concerned.

(*m*) I should say that the most important suggestion that I could make in regard to diving would be that of the evolving of a shallow water diving outfit for the use on board ships working on propellers, and other work on ships' bottoms. The weights furnished with the regular diving outfit are too cumbersome and too heavy for this type of work, and it has been my practice to reduce the weights on one belt of the outfit until the amount of weight gave satisfactory results for shallow water. This same result could be better accomplished by providing each vessel with an outfit properly designed for this class of work.

2. Am sorry that I have not been able to shed more light on the questions which you have asked, but am getting away from diving and ordnance end of our profession in the last four years; in fact, in the last year since being stationed here with the machinery division, engines and boilers have become much more familiar to me than guns and so forth.

Trusting that you and your family are all well, I remain,

Yours, sincerely,

H. A. NEVINS.

UNITED STATES NAVAL STATION,
Cavite, P. I., June 22, 1914.

From: Chief Gunner R. H. Cheney, United States Navy.
To: Gunner G. D. Stillson, United States Navy.
Subject: Comments on submarine armor, diving apparatus, appliances, diving operations, etc.

In reply to your letter I would make the following suggestions:

(*a*) The rubber dress as now made can not be improved on. The breastplate should be narrow in front so as not to interfere with the diver's arms, and should have on the front two rings, one on each side, to secure the life line and hose too.

The air hose should be attached to the back of breastplate instead of helmet. A check valve should be used as usual, also a fixture for the entrance of telephone cable, which would be secured to air hose by seizing or light metal clamps.

The helmet should not have any other fixture than the escape valve on it, the valve being capable of adjustment while below.

The helmet should be secured to breastplate by means of the interrupted screw system and should have handles on either side to facilitate screwing on. The faceplate should not be removable.

The telephone should be fitted with a head clamp so that a receiver is over each ear. The transmitter being also secured to the clamp so as to be near the lips of the diver. A short flexible wire being attached to allow for movement of the head, etc. A supplementary air-purifying device or supply could be carried on the back of the diver, only to be used in case of accident to the pump or air hose.

I believe such devices are used in Europe.

(*b*) No suggestions.

(*c*) From personal experience, the writer has the following criticisms to make on the diving apparatus in use in the service:

All gear, with the exception below noted, is excellent and can hardly be improved upon.

The writer was diving in Samoa, inspecting dredging operations, and had to come to the surface to make frequent reports. It required at least two to three minutes to remove the helmet, while the contractor's diver had his helmet off usually in about 30 seconds. The same occurred when replacing the helmet. He used the screw-jointed helmet. On account of time lost, the writer was loaned a helmet by the contractors, and a great deal of time was saved. The helmet is unusually heavy, also the breast plate, and should be lightened. This was probably due to the fact that whoever designed them only took account of the outside pressure on them and made them heavy enough to withstand it, forgetting that the air pressure inside had to be a little greater than the outside pressure in order to secure circulation in the air system, thus balancing the outside pressure. In case of accident to the pump the check valve in hose line prevents the inside pressure from escaping, thus still maintaining the equilibrium.

The breastplate is too full in front and interferes with the divers arms, and prevents him from climbing lines, etc. The breastplate of the Siebe-Gorman type has not this defect and when using it the writer had no trouble in climbing or working under water.

The weight belt is usually too heavy for ordinary work, and the weights should be so secured so that several can be removed according to the working view.

The writer does not desire to make any criticisms as to methods, except that he personally does not believe in helmet diving, except in very shallow water, and where there is no chance of fouling, and this method only to be used in water not exceeding 30 feet in depth, and then only by an expert swimmer.

(*d*) The writer has not had any experience in large operations, but would state that usually in such operations the only change in apparatus is that a steam-driven pump is used for the air supply in conjunction with an air reservoir, the air being pumped up through water to cool it.

All expert divers descend on a line. The method used is to straddle the line, grasp the line with the left hand about the height of the face, the right hand grasping the line where it comes out in rear between the legs thus making a sort of a half loop that the right leg rests upon; by letting the rope run out between the hands, complete control is maintained of the descent by the diver. The descending line usually acts as a guide line to guide the diver to the place of work.

The time taken in descending varies the writer when diving in 45 feet of water went right down without stopping and ascended in the same way. This is not practicable with all men. The usual method in water over 20 feet is to stop at say every 20 feet, approximately, and remain for at least a minute until a depth of 80 feet is reached when the pause should be for two or three minutes, thus making the time of descent, say, to 100 feet, approximately 8 to 10 minutes; in ascending it should take at least twice as long to reach the surface.

The writer has remained under water, depth 45 feet, for over 4 hours, and experienced no evil results; about 1 hour and 40 minutes at 80 feet, same results, and descended to a depth of 168 feet, having landed on the edge of a coral reef in about 100 feet, and climbing down the side of the reef to the greater depth, remained approximately 5 minutes, felt slight giddiness and was light headed, but when the surface was reached felt no evil effects. The diver working for the contractor building the coaling station in Samoa, remained under water for 3 hours and 45 minutes, approximately, in a depth of water ranging from 100 to 120 feet, and I was informed by said diver that he had worked 4 hours under water in a depth of 150 feet while working on a wreck in Puget Sound. At this time he was 50 years old and had been diving for about 30 years; this was in 1900. I saw the same diver in 1911 and found him partially paralyzed, having lost the use of his right hand and this was the result of a blood clot formed on the brain while working on a diving operation, due, no doubt, to the fact of either coming to the surface too suddenly or descending too rapidly.

(*e*) The writer while diving at Samoa, in about 35 feet of water, lost his hold on descending line and dropped about 15 feet, due to ignorance on the part of man tending who was new to the work. The sudden drop compressed the air in the suit, and so much heat was generated that I was almost asphyxiated and lost consciousness for about a minute. I recovered rapidly and returned to the surface; no after effects. A man in the employ of the contractor was broken in by the diver, and worked for several months when he fell into a hole, made by the spud pole of the dredger, and it rendered him unconscious for several minutes and scared him so that he never dived again. I have heard that several divers have been killed in falling, but can not recall names or places.

In Olongapo recently a gunner's mate named Young was drowned while diving. He only used a helmet and life line, these fouled on some moorings, and Young evidently slipped his helmet expecting to rise to the surface, but he had forgotten the line securing the helmet to his shoulders and was held by that and was drowned before he could remove it; he was working in about 85 feet of water.

I do not know of any accidents to apparatus.

(*f*) Some divers have worked in 150 feet of water, but they are exceptionable men. The writer believes that 120 feet is as deep as most divers can work.

(*g*) No ideas.

(*h*) Nothing new to offer in way of advice; the usual precautions embodied in diving manual cover this. Of course, the nature of some jobs is such that no hard and fast lines can be laid down. The writer believes that in shark-infested water, exploding several small charges of dynamite or other explosives would effectually clear the water from these pests by scaring them away.

(*i*) The ideas embodied in previous paragraphs, is the writer's idea of the most efficient form of diving apparatus, i. e., a fiber-cloth dress secured to a breastplate in the usual manner, the breastplate having a bayonet screw joint for securing to it the helmet, air to be supplied by means of an air pump. The present type is admirable. Air-supply inlet to be on breastplate, also telephone inlet, nothing on helmet except the escape valve. The hose and life line to be secured to front of breast plate, leaving the helmet clear of everything, thus avoiding the necessity of having to clear the same every time the helmet is taken off.

(*j*) I would suggest the following organization, and course of training:

One officer in charge of training, etc.

One medical officer, and resuscitating appliances (pulmotor, air room for bends and usual drugs, etc.), also for physical examination of candidates.

One master diver, three assistant divers, instructors.

The primary instructions should take place in an instruction tank that should be practically of these dimensions and shape:

A circular iron tank of at least 20 feet depth and to have a diameter of 20 feet, a movable platform by which this depth can be regulated, to be above ground, and to have at 15 feet depth and near the bottom, glass ports through which the instructor and pupils can view the diver in the tank, so that faults can be observed and thus corrected.

After qualifying, then outside work in deeper water proceeding by increments of 15 feet until a depth of at least 100 feet is reached, which should qualify the candidate.

The course of instructions should follow in the sequency.

First week: Instruction in nomenclature of suit, accessories, etc., how to dress and undress, precautions to be observed, care of apparatus, how to send signals.

Second week: Morning, primary diving practice in tank, 1 to 15 feet depth; afternoon, care and repairs to dress, how to patch, secure new cuffs, etc., also instructions in knots, hitches, bends, etc., and methods of slinging various objects.

Third week: Tank work in 30 feet, slinging various objects, using tools under water, etc., instructions in use of explosives, the effect of same, the care and precautions to be observed in use of explosives.

Fourth week: Instruction in tank which should be darkened so that all work must be done by sense of touch, also working double with an assistant instructor under same conditions, fouling of hose and line, how to clear same, etc.

Fifth week: Outside work begin in 30 feet, on muddy bottom, on sandy bottom, on rocks, etc., in tideway, in quiet water.

Fifth and sixth week: Outside work until 100 feet is reached.

Seventh, eighth, and ninth week: Practice in medium depth in searching for lost objects, methods of workings, and practical work of all kinds, i. e., an old launch could be sunk and recovered by diver, anchors and various other objects recovered, work on bottom of vessels, method of slinging stages, etc., repairs to ship's bottom if practicable, otherwise theory.

Tenth week: Examination and tests.

(*k*) The pay of a diver should be based on a dive, a dive to consist of from 1 minute to 4 hours, the pay should be $5 per dive; that is, if a diver can do a piece of work in 10 minutes he would not be tempted to loaf below, so as to make a long job of it, which is often done.

A diver would thus in an 8-hour day earn $10, i. e., two dives.

All qualified divers should have diving practice every month and should be paid one-half pay for this; he should if possible go down in from 30 feet, and then advance to 60 feet, and then to 100 feet. This practice work is very essential and should never be omitted.

(*l*) An 8-hour day in warm temperatures, in water 80 feet deep; in water 100 feet deep, 4 hours. In cold water it rests entirely on the diver. The writer has been below water for over an hour in Newport, R. I., in the dead of winter in a freezing temperature; the hands were very much puffed up, and the dress could not be removed for some time; no other evil effects.

(*m*) The writer would make the following suggestions:

Never dive when the ear drums do not snap when you swallow; deafness is liable to result. This generally is caused by a cold and unless very bad, can be remedied by pouring warm olive oil in ears and letting it remain for an hour or so.

R. H. Cheney.

U. S. S. "Milwaukee,"
Bremerton, Wash., July 14, 1914.

From: Gunner F. G. Keyes, United States Navy.
To: Gunner G. D. Stillson, United States Navy.
Subject: Diving apparatus.

1. As my diving has been limited to minor operations, I am unable to offer suggestions of any practical value as to diving apparatus.

2. I have used both the bayonet jointed helmet and the one held to the breastplate by five dogs and nuts; I prefer the former. Have also made and used a much smaller pad than that supplied with the service diving outfit, and found it more comfortable.

F. G. Keyes.

U. S. S. "Minnesota,"
Off Tampico, Mexico, July 20, 1914.

From: Gunner Frederick Evans, United States Navy.
To: Gunner G. D. Stillson, United States Navy.
Subject: Submarine armor, diving apparatus, appliances, diving operations, etc.

1. In reply to your letter, regarding information covering the above subjects will state that I will endeavor to answer the same, according to the several subjects under the tabular list, with the exception of subject *b*, *c*, *d*, and *m*, which subject I have nothing to state or recommend.

(*a*) The present apparatus for diving I have found to answer all requirements for all naval work, except, perhaps, the relief valve on the helmet might be placed in a more accessible place; its present position being too far toward the back, so much so that when the arm becomes inflated, as it sometimes does, it can not be reached.

I would recommend that it be placed as far forward on the helmet as the helmet's construction will allow.

I also recommend that nothing but cable laid life line be issued to the service, for it does not give any trouble with turns and kinks as does a plain laid line.

I would also suggest that the heart-shaped breast weights of about 40 to 50 pounds be added to the equipment in addition to the belt.

I would strongly recommend that no departure be made from the reliable hand-power pump to an engine or motor driven one, engines and motors, as we know, being unreliable.

(*b*) In my experience I have been with but one accident and that was to myself. While diving at Hampton Roads, Va., at night, I felt that too much air was being received. After adjusting the relief valve to its limit, I made the proper signals for less air two or three times, and while I could tell by the stroke of the pump, that was barely turning over, still too much air seemed to be supplied. The suit was now completely inflated and my arms extended so that I could not reach my life line or hose to make signals, this being further hampered by the fact that the life line had gotten under my arm and extended up my back. I now endeavored to signal to the boat by squatting suddenly with my body, or, as it were, to signal with my body. This I found impossible, due to the buoyancy of the suit. While making these endeavors I lost consciousness, for I remembered nothing further until I felt the bright rays of a searchlight in my eyes and found that I was prone in the diving boat. I later learned that I was discovered floating on the surface, astern of the diving boat. The depth of water at Hampton Roads is about 14 to 15 fathoms. I never did discover the cause of this accident, but I believe it was due to too heavy a relief spring.

(*f*) I believe the maximum depth for naval divers, who but rarely ever dive, should be 100 feet. No attempt should be made to send down any but a most experienced diver and of extra strong physique and who has been having recent experience at greater depths. Seventy-five feet should be considered as the maximum depth for useful work, for the average naval diver, for any length of time.

(*g*) It is considered that no apparatus can be adapted for use for any greater depths; for the ill effects on the diver are caused by great pressure. No matter if some arrangement were designed to withhold the water pressure before it can be released. There is but one way to reduce this pressure; that is, to building an armored suit to withstand the water pressure and to use two air hoses, one a supply and the other an exhaust. Of course we know that such an apparatus is impracticable and the diver may better stay on top than endeavor to accomplish results in such a thing, except perhaps, for sight-seeing dips and picture taking.

(*h*) The rules laid down in the diving manual for the preparation and tending of the diver, I think fully cover this subject.

(*i*) I am acquainted with but one type of diving gear, that of A. J. Morse & Co., of Boston; this has always been satisfactory, with the exceptions as enumerated under subject (*a*).

(*j*) In addition to teaching a student how to be at home and rest easy in a diving suit below the surface, it should above all other things be taught him how to use his head, for he and he alone can get results while below the surface. One of the hardest difficulties, in addition to the apparent timidity and lack of endurance, I find, with ordinary naval divers, is to get them to do what they put the suit on for and dive to do.

The greatest work naval divers are called on to do is searching, and usually in muddy bottoms, where they are constantly in darkness, as it were. In this work, the diver must be sure that he has covered every bit of the ground within the radius of his life line and hose. It is a fact that under water there is no sense of direction, especially at any depth, the sunbeam-slant idea to the contrary notwithstanding.

Current may give a general idea, but the diver can not tell with certainty where he is.

The student should be taught that under all circumstances of search he can tell just where he is and how much ground he has covered and know to a certainty that, that for which he is in search for is not in the covered ground. This can be done in the following manner: By the use of our old stand-by, the circulating line and an additional one which we might call the circle indicator line. This line is but to indicate to the diver when he has completed a circle, thus assuring of wholly covering that ground within that radius. It is made fast to the same weight as the circulating line, its other end being also weighted, stretching along the bottom. The first thing the diver will do upon reaching bottom, he having descended on the circulating line, the end of which will be retained in the boat until the diver is ready for it, is to run out the indicator line in any direction until it is laid taut on the bottom; he now returns along the line to circle weight and signals for the end of the circling line, which is given him, or, which is a better method, this line is kept long enough so that the diver works with the bight, the slack being paid out from the boat.

It is readily seen that by the use of the indicator line the diver can tell just what part of the circle he is in at all times.

He shall be taught how great a radius he must increase for each circle he makes, according to the nature of the article for which he is in search, viz, if he were in search of a torpedo that had run in the mud, he would expect to find a hole, which would be no smaller than 4 feet in diameter; thus he would increase the radius of his circle by 4 feet. If the torpedo has sunk clear to the bottom and was thus lying on the bottom, or he were in search of an anchor, whose stock would be clear of bottom, he would then go to the very end of his life line, and circling on it, would use his circling line as a feeler. This is done by keeping the circling line a little slack, being sure that it is always on bottom and the life line taut; in fact, let the life line help to support him by its holding his weight, which is not only to the purpose but relieves him, especially if it be very muddy. Occasionally, not too often, he will stop and carefully haul in the slack of the circling line, to assure himself that too much slack is not being gathered, for he may not be making a circle coincident with the one with which his circulating line is the radius, for his radius is the life line, the center of which is the boat, and therefore perhaps far removed from the spot where the circulating weight may be. It is surprising how light a touch can be felt on this line. If he gets a bite, he shall drop the circulating line on the bottom right where it is, and run along it until he comes to the obstruction, and if it be other than the object of his search, he shall clear it, run out again along the line without disturbing it from the bottom until his life line is again taut and he is right where he stopped, and is ready to start again. He must be impressed with the importance of not moving the line where it lays at rest while he is going in and out. After he has reached his indicator line again, thus finishing his circle, he will go in along the circulating line to the weight, this to assure him that it is clear. Perhaps he may find a round turn around what he is looking for. Of course, on rocky bottoms, or when there are numerous obstructions, this method would be impracticable. Diver's judgment will tell him what method to use.

To readily teach the diver to think and act for himself, and to show others how easy it is to miss ground on a search, I would suggest that all instructions governing work to be done be given above water, but simulated by the same conditions that exist under water as regards the divers' difficulties and inconveniences, that it may be clearly shown to the instructor that the student has the head so necessary for efficient diving, viz, every known work and problem in diving, and probable ones, should be tabulated and a method of procedure established along known sensible line to accomplish the desired end; for instance, search work, rigging gear for a ship's bottom, putting a plate on ship's bottom, especially at the bends; preparing submerged craft, large and small, for hoisting; laying foundations under water; repairing pipes, etc.; how to keep themselves clear when entering wrecks; to clear themselves if fouled; what to do in emergencies, air cut off for some reason or other, etc. All of these or any other subjects that might be beneficial should be taught the diver or student as above stated; that is, under as near diving conditions as possible. To do this, I would suggest using a suspended platform, to simulate a boat over clear ground or a floor, large enough to be covered by a reasonable radius by the diver or student, say 150 feet. I consider it of importance that the life line and hose should lead up from the diver or student and be unobstructed by any supports of a platform. The diver should be dressed on the platform without weights, with ordinary shoes, and faceplate off, and thoroughly blindfolded, this latter is the most important part of the instruction the teaching of the student to think and act in the dark, which is the usual condition of diving. The diver is now instructed to do some particular work and how it is to be done, and is lowered to the ground or floor below, preferably ground, and he proceeds to carry out instructions, the rest of the class watching, to profit and learn by his errors. It can soon be seen what a man is capable of doing in a diving suit under favorable conditions, and if he does not show the proper aptitude and indications of a thinking head, it is folly ever to allow him to enter water. This is better done by giving him problems to overcome, whereby his own judgment, rather than any defined rules, will dictate his actions, as for instance, fouling him.

(*k*) I would suggest pay according to the depth of water and circumstances, such as temperature and character of work to perform.

Any diver who dives in water over 70 feet should get double the rate of pay which is now given; for no one but those who have been down this and greater depths know the physical sufferings that must be undergone, except perhaps those who are the most strong. I but need to mention a groggy diver, even in ordinary depths, to take from one to two hours to recuperate.

(*l*) Divers should never be down in any depth, or under the most favorable circumstances, a longer period than four hours. It must be remembered that the mere fact that the diver being so heavily weighted is a physical exertion in itself, the act of dressing the diver putting him under great physical stress. If the temperature is cool, the diver may work three hours under the same conditions any depth up to 70, and two hours at a greater depth, not to exceed 75 feet, and two hours if greater than 75 feet, should constitute a day's work if the bottom is good the weather clear and the work not too strenuous. In tropical climates or on hot summer days, or where there is great exertion required in the work to be carried out, whether cool or hot, or for greater depths than 70 feet, no predetermined workday should be considered, but should be left alone to the diver's endurance and ability.

FREDERICK EVANS,
Gunner, United States Navy.

U. S. S. "NORTH DAKOTA,"
Vera Cruz, Mexico, August 20, 1914.

From: D. F. Mulvihill, gunner, United States Navy.
To: G. D. Stillson, gunner, United States Navy.
Subject: Submarine armor, diving apparatus, appliances, diving operations, etc.

(*a*) Diving suits with laced legs to be provided; longer handles for the pump; helmets fitted with spit cocks; test tanks to be furnished.

(*b*) It is recommended that a suitable telephone be furnished, so that the tender will be in communication with the diver at all times. Breast weight to be used instead of the belt. Divers to be classified—expert, first, and second. Expert divers to make a dip monthly over 80 feet, semiannually over 100 feet; first and second class, 60 feet once a quarter. Recommend that new system of diving be adopted.

(*c*) The method of diving as now used in the United States Navy should be discontinued and the improved method adopted. The Morse telephones are not satisfactory nor are the suits. Belts are too heavy and tire the diver.

(*d*) A. L. Johnson, gunner's mate, first class, pains in kidneys not due to decompression, but probably due to wearing heavy belt.

G. H. Turner, turret captain, first class, pains in arms not due to decompression.

C. E. Anderson, chief turret officer, searching for lost torpedo at depth, was brought to surface too soon. Had headache and started to vomit. Two days afterwards remained on bottom 2 hours and 30 minutes. The chief gunner's mate in charge of launch claimed it took 46 minutes for the decompression, making 3 hours and 16 minutes altogether. Diver left water in good condition. About 10 p. m., felt pains in the joints of arms and legs; also around groins. Went to sick bay and was given some local treatment. I was not notified; in fact, I did not know that Anderson was on sick list. Anderson claims the pains lasted for about 20 hours. Now, this is a plain case of nitrogen trouble, and I could have relieved the diver had I been notified.

F. M. Euchstaedt, seaman, after being on bottom for 1 hour and 30 minutes at 80 feet, signaled to come up. Was hauled over to descending line and gave (one) pull, meaning he had hold of descending line; seemed to be coming up too fast. I then stopped pump, but diver came to surface from 80 feet in about 2 minutes. I took off faceplates and asked diver what was the matter, and found out that he had closed escape valve entirely. I sent him down to 30 feet for 5 minutes, 21 feet for 15 minutes, and 10 feet for 15 minutes. Diver left water in excellent condition.

(*e*) While dressing diver both cuffs were torn, due to the rubber being decayed.

Air gauge would not register; found out that three-way valve was put in wrong.

(*f*) About 90 feet with one good pump making 30 revolutions.

(*g*) By connecting up two pumps in series. This has been done on this ship, but has not been tried out.

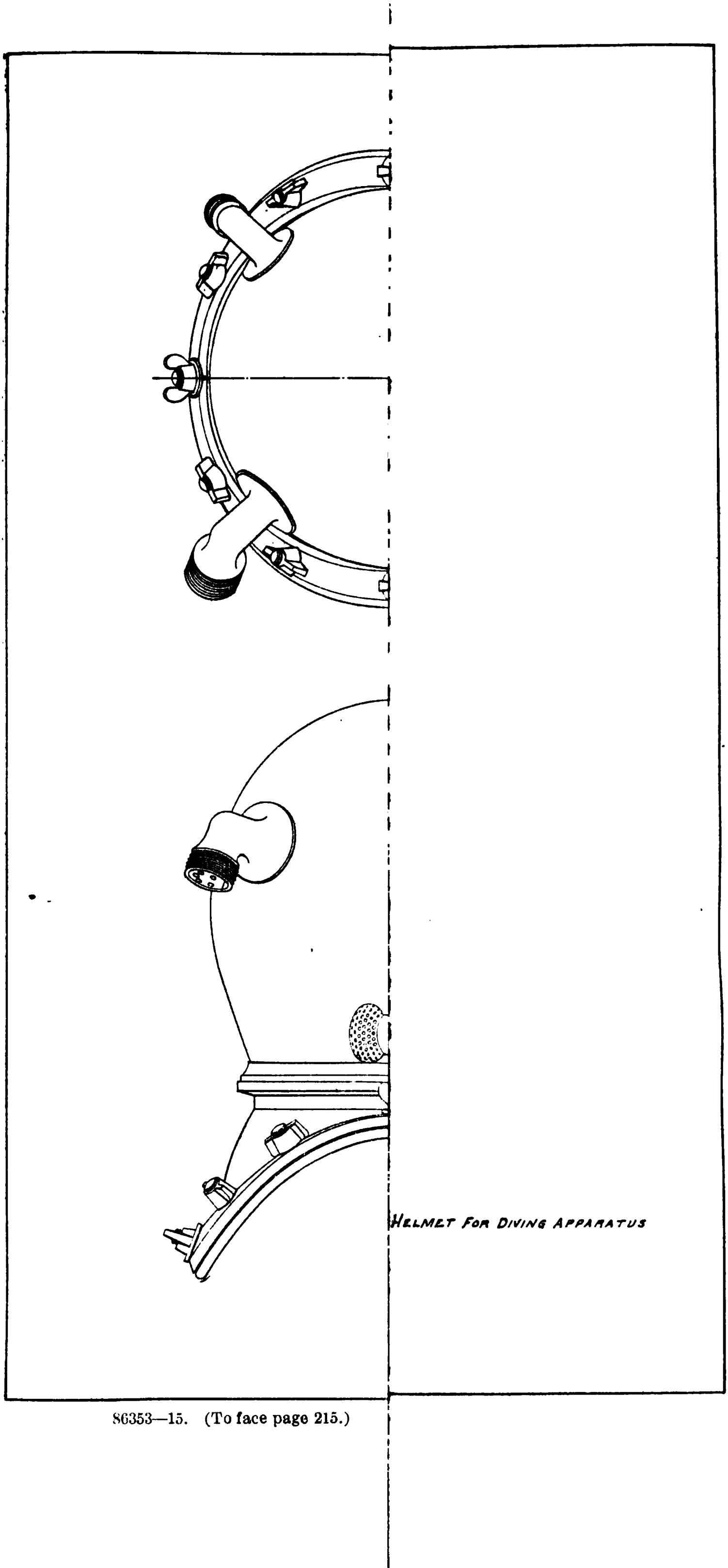
(*h*) By having competent tenders that understand the new method of diving; also by using the tables that are used in the British Navy, and that all qualified divers understand the Schafer method of resuscitation.

(*i*) Siebe, Gorman & Co. (Ltd.) improved laced leg suits and telephones.

(*j*) Course to be twelve weeks.

First week: Instruction in the method of decompressing, dangers of nitrogen bubbles, etc.; signals used; telephones.

Second week: Pumps, how to line up, replace packings, valves, springs; all tests.
Third week: Repairs to suit, replace cuffs, collars, etc.; how to make patches
Fourth week: Diving in tank.
Fifth week: Diving in sea water up to 90 feet.
Sixth week: Diving in sea water up to 90 feet, doing actual work.
Seventh week: Diving in sea water up to 120 feet.
Eighth week: Diving in sea water, doing actual work up to 120 feet.
Ninth and tenth weeks: Same as eighth week.



86353—15. (To face page 215.)

Eleventh week: Care and operation of apparatus.

Twelfth week: Reviews.

(*k*) Over 80 and 90 feet, pay to be increased to $1.40 per hour; 90 to 100 feet, $1.60 per hour; 100 feet and over, $2 per hour.

(*l*) Four hours to constitute a day's work up to 80 feet; three hours at 90 feet; two hours at 100 feet; one hour at 120 feet; actual time on bottom.

(*m*) That a circular letter be sent to commanding officers, prohibiting diving to be carried on in deep water under present system; also that ships' doctors give a lecture at least once a quarter to the men in regard to the decompression and the danger of the formation of nitrogen bubbles.

D. F. MULVIHILL.

[Inclosure (Z).]

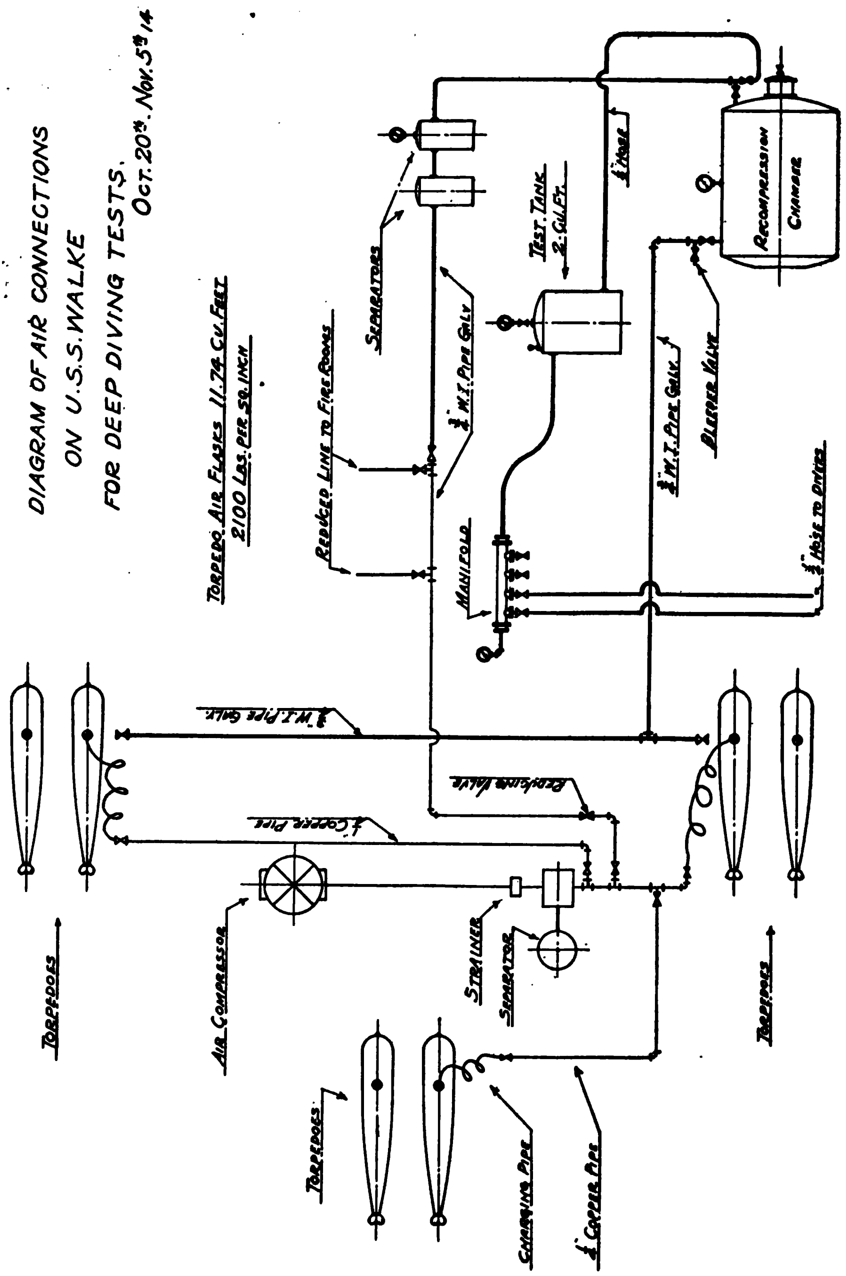
IMPROVED DIVING HELMET.

The helmet shown in drawing meets all the requirements mentioned in paragraphs Nos. 53 to 61, inclusive. The helmet is made slightly larger and the shape is changed to permit the use of the improved telephone.

[Inclosure (Z-1).]

ARRANGEMENT OF DIVER'S AIR SUPPLY ON BOARD U. S. S. "WALKE."

For details see reference (*a*), referred to in report 67-T.



[Inclosure (Z-2).]

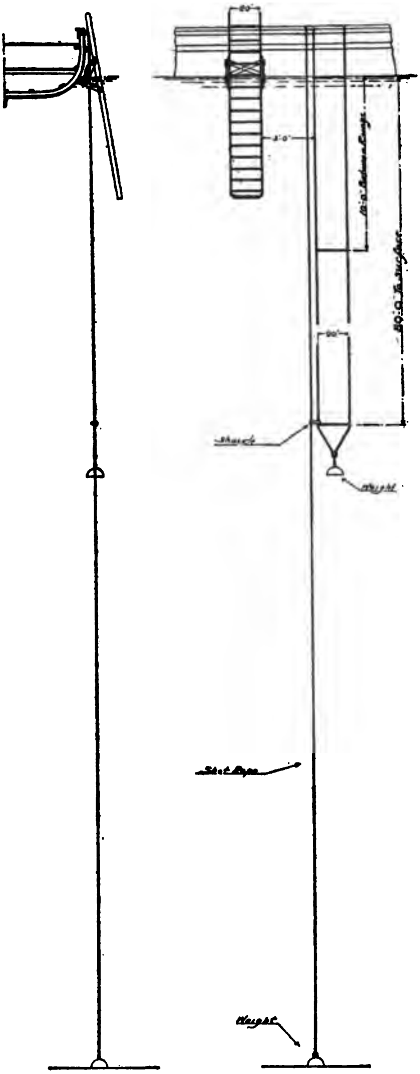
METHOD OF ARRANGING DIVING LADDERS, ETC., IN SAILING LAUNCHES, ETC.

The diving ladder is first shipped in place over the side of the boat; keep in mind the position of diving pumps, etc. Sending the diver down over the side is preferable to sending him down over the stern of a boat, as, when he crosses under the boat on bottom, his lines can be kept clear of ladder, etc.

The descending line must be weighted sufficiently for it to remain on bottom. If heavy weights are used, diver must be prepared to cut them free in case of becoming badly fouled.

The Jacob's ladder is weighted sufficiently to cause it to hang plumb in the water. To get it over the side, hang weight overboard, secure edge of ladder, as shown by a loose shackle, and then lower as many rungs under water as there are stages of decompression. For instance, if the diver is to stop first at 30 feet, lower the fourth rung to the water's edge; this will place bottom rung 30 feet from surface, etc.

The descending line must be between diving ladder and Jacob's ladder, and the latter must be abaft the diving ladder or on the lee side of it with reference to direction of the current.



ARRANGEMENT OF LADDERS·
FOR DIVING FROM SAILING LAUNCH

APPENDIX 1.

87-TJ

NAVY YARD, NEW YORK,
HULL DIVISION,
November 5, 1914.

From: Gunner G. D. Stillson, United States Navy.
To: Industrial Manager, via Construction Officer.
Subject: Deep-diving tests, report of, accomplished from U. S. S. *Walke*.
References: (*a*) Bureau C. & R. letter, Oct. 7, 1914, No. 957-A168-S11/4; (*b*) Commandant's indorsement, Oct. 8, 1914, No. 120-112; (*c*) Bureau C. & R. radio, Oct. 15, 1914, No. 957-A168-S; (*d*) Commandant's indorsement, Oct. 15, 1914, No. 120-121/120-112; (*e*) Department's radio, Oct. 20, 1914, No. ; (*f*) Commandant's indorsement, Oct. 20, 1914, No. 120-132/120-112.

1. Preparations for deep-diving tests at sea were completed on board the U. S. S. *Walke*, at the navy yard, New York, N. Y., October 20, 1914.

2. In connection with the above, the following work was accomplished by the navy-yard force:

(*a*) Recompression chamber placed on board and secured for sea.

(*b*) Temporary air-pipe lines run between recompression chamber and ship's low-pressure (100 pounds) air line.

(*c*) Branch pipe connection run between diving manifold and torpedo charging line by way of reducing valve in low-pressure air line.

(*d*) Two torpedo air separators installed in diving air line.

(*e*) Reserve torpedo air flask connected to recompression chamber for raising pressure in same quickly.

(*f*) Manufactured one wooden diving ladder and one special Jacob's ladder.

3. The recompression chamber was fitted with electric light, heater, and telephone; and provided with hospital stretcher, pillow, blankets, and mattress; two suits of clean dry woolen underwear; a watch for timing operations; typewritten instructions; a copy of signals; and a notebook and pencil.

4. Three complete sets of ordinary diving apparatus (minus diving pumps) were provided with necessary spare parts. etc. In addition the special diver's air-control valves were fitted in place and used throughout tests, also two special diving telephones (made at the navy yard by the divers under my direction) were provided. The diving helmets used for these tests were the two purchased especially for the deep-diving tests. These have been extensively experimented with and several minor changes have been made in them.

5. October 20:

P. M.—Tested out installation and found same satisfactory. The quality of the air delivered from the ship's compressed air system was carefully tested and found suitable for respiration purposes.

6. October 21:

A. M.—Got underway at 11 o'clock and proceeded on duty assigned.

P. M.—Anchored off Orient, Long Island, at 3.40 o'clock, in 15 fathoms of water.

7. October 22:

A. M.—Weather clear; light breeze from east-northeast; flood tide; velocity of tide 3.1 knots per hour. Charged two torpedo air flasks. Tested reducing valve and found same out of order and started a machinist's mate overhauling same. Tested recompression chamber and found same, with all apparatus and connections, satisfactory. Chief Gunner's Mate Crilley and myself were compressed in chamber to

75 pounds pressure per square inch by gauge in three minutes. Passed Assist. Surg. G. R. W. French, United States Navy, in charge of test. All preparations were made for diving to commence at turn of tide.

P. M.—Diver Drellishak was selected to make first dive. The tide was running strongly to flood until about noon, when it slacked for 20 minutes and turned to ebb. Velocity measured at time of descent was about 3 knots. It was a difficult matter to get descending line (fastened to an 80-pound weight) on the bottom. Diver descended without difficulty until near the bottom, when the tide lifted the weight and diver combined. Slacked off descending line and lowered diver and weight to bottom. He landed several feet abaft ladder. The strain on air hose and telephone line (no life line used) was considerable. All communication to diver by telephone. As it was not desirable to take any undue risks on the first descent the diver was called up. No allowance was made for decompression. As the ascent was made uniformly and rather rapid the diver was quickly undressed and directed to enter the recommpression chamber, compressed to 20 pounds pressure and then decompressed leisurely in two stages. Diver's condition normal. Diver reported he could have negotiated a stronger tide but did not think he could have accomplished much work without a special rig for holding himself against the current.

DETAILS OF DRELLISHAK'S DIVE.

[Depth, 84 feet; temperature of water, 62° F.; sea smooth; ebb tide, 3.1 knots.]

Entered water	2.30
Reached bottom	2.35
Called up	2.40
Left bottom	2.41
Left water	2.51

Descending line weighted with 80-pound weight. Weight landed about 30 feet abaft diving ladder. Diver had trouble in getting down. Weight swept off bottom by tide. Diver telephoned that he was standing on weight which was not on the bottom. Lowered weight and diver to bottom. Landed them several feet farther abaft of the ladder. Diver reported that weight was lifting off bottom, which was of smooth hard sand covered with white pebbles. Diver called up. The ascent due to the trend of the descending line was made at a considerable angle. The rule for diving in a tideway is that when a 50-pound weight will not stay on bottom diving operations are impracticable. In this case an 80-pound weight would not remain on bottom. The drag on the air hose and telephone cable (stopped together) was considerable. No life line or signal line was used. Diver was not distressed by effects of tide and with a special under-water rig could have remained under water indefinitely. Light on bottom fair, having appearance of dense shade. Due to short decompression the precaution was taken to place diver in recompression chamber immediately upon his arrival on deck. Pressure was applied and decompression was accomplished in the regular manner. As it was considered desirable to make trial dives under more favorable tidal conditions anchorage was shifted to a position off Roanoke Point, Long Island, in 15 fathoms of water.

8. October 23:

A. M.—As a brisk wind had been blowing during the night the sea was choppy and conditions were unsuitable for experimental work. Toward noon the weather moderated and preparations were made for diving.

P. M.—The following dives were made:

DIVER STILLSON.

[Depth, 88½ feet; temperature of water, 62° F.; sea smooth; ebb tide, ½ knot.]

Entered water	11.41
Reached bottom	11.44½
Left bottom	12.00
Reached 20 feet	12.04½
Reached 10 feet	12.07½
Left water	12.15

Time on bottom, 15½ minutes.
Time under water, 34 minutes.
Total decompression, 15 minutes.
No light on bottom, which was of soft gray mud.

DIVER NIELSON.

[Depth, 90 feet; temperature of sea water, 62° F.; sea smooth; ebb tide, ½ knot.]

Entered water	1.48
Reached bottom	1.49
Started up	2.05
Reached 20 feet	2.08
Reached 10 feet	2.11½
Left water	2.17

Time on bottom, 16 minutes.
Time under water, 29 minutes.
Total decompression, 12 minutes.
No light; diver walked around on bottom, which was of soft gray mud.

DIVER CRILLEY.

[Depth, 90 feet; temperature of water, 62° F.; sea smooth; ebb tide, ½ knot.]

Entered water	2.34
Reached bottom	2.36
Left bottom	2.58½
Reached 20 feet	3.01
Reached 10 feet	3.06
Reached surface	3.16½
Left water	3.17

Time on bottom 22½ minutes.
Time under water 43 minutes.
Total decompression 18 minutes.
Diver walked around on bottom. No light on bottom, which was of soft gray mud.

DIVER ANDERSON (NAVY YARD, NEW YORK DIVER).

[Depth 90 feet; temperature of water 62° F.; sea smooth; ebb tide ½ knot.]

Entered water	3.34
Reached bottom	3.37
Left bottom	4.01
Reached 20 feet	4.04
Reached 10 feet	4.09½
Left water	4.24

Time on bottom 24 minutes.

Time under water 50 minutes.

Total decompression 23 minutes.

Diver walked around on bottom; no light. Diver brought up a piece of kelp to surface.

Anderson is an expert and skillful diver. First experience at diving with air furnished by other than hand-driven diving pumps. He stated that the experience was a revelation to him and that at this depth he felt more comfortable than when diving in the shallow water of the New York navy yard and using a hand pump. It was the first time he had ever used a telephone under water successfully and the efficiency of the new diving telephone was a surprise to him.

9. October 24: *Walke* ran into New London, Conn., for provisions, etc.

10. October 26:

A. M.—Left New London for diving grounds. Arrived off Roanoke Point, L. I., at noon, anchored in 23 fathoms.

P. M.—The following dives were made:

DIVER CRILLEY.

[Depth 136½ feet; temperature of water 62° F.; sea choppy; ebb tide ½ knot.]

Entered water	1.57½
Reached bottom	2.00½
Left bottom	2.20½
Reached 40 feet	2.25
Reached 30 feet	2.27
Reached 20 feet	2.33
Reached 10 feet	2.43
Left water	2.58

Time on bottom 20 minutes.

Time under water 60½ minutes.

Total time of decompression 37½ minutes.

Diver on the ascent overshot the first stop by 20 feet, but descended within one minute's time to first stop of 40 feet.

Small whitecaps, wind southwest, force 3; no light on bottom, which was of soft gray mud. Diver walked around on bottom holding on to distance line.

DIVER ANDERSON (NAVY YARD, NEW YORK DIVER).

[Depth 136½ feet; temperature of water 63° F.; sea choppy; ebb tide ½ knot.]

Entered water	3.17
Reached bottom	3.19
Left bottom	3.26
Reached 40 feet	3.28
Reached 30 feet	3.29
Reached 20 feet	3.33
Reached 10 feet	3.39
Left water	3.45

Small whitecaps, wind southwest, force 3; no light on bottom, which was of soft mud. Diver walked around on bottom holding on to distance line.

DIVER DRELLISHAK.

[Sea choppy; temperature of water 63° F.; depth 136½ feet; ebb tide ½ knot.]

Entered water	4.01½
Reached bottom	4.02½
Left bottom	4.25

Reached 40 feet	4.26
Reached 30 feet	4.29
Reached 20 feet	4.34
Reached 10 feet	4.44
Left water	4.57

Time on bottom, 22½ minutes.

Time under water, 55½ minutes.

Total decompression, 32 minutes.

Small whitecaps; wind from the southwest; force, 3. Air hose lowered faster than diver; and when he landed found himself foul in coils of same, which he cleared without difficulty. No light on bottom, which was of soft gray mud. Diver walked around on bottom.

11. October 27: High wind from northwest and heavy sea running; unable to dive; *Walke* ran across Long Island Sound and anchored under the lee of the breakwater off New Haven, Conn.

12. October 28:

A. M.—Got underway and proceeded to a location off Eatons Point, L. I.; anchored in 28½ fathoms of water and made preparations for diving.

DIVER NIELSON.

[Depth 171 feet; temperature of water 61° F.; moderate sea; velocity of tide 1.3 knots; moderate breeze from south southwest by west.]

P. M.—

Entered water	1.07
Reached bottom	1.10
Called up	1.22
Left bottom	1.23
Reached 50 feet	1.30
Reached 40 feet	1.37
Reached 30 feet	1.41
Reached 20 feet	1.51
Reached 10 feet	2.09
Left water	2.25

Time on bottom, 13 minutes.

Time under water, 78 minutes.

Time of decompression, 62 minutes.

On the descent the diver found the descending line tending at a considerable angle; but he continued the descent. He found the weight off the bottom and telephoned to have it lowered. The line was slacked off several fathoms, but the weight (100 pounds) refused to remain on the bottom. The diver left weight and went to the bottom, keeping hold of the distance line. He then found that the weight was moving rapidly through the water and felt the effect of the tide. During this time the ship was swinging over the diver and all lines were foul under the ship. Air was being taken from a partly charged torpedo air flask, and as the supply was running low the compressor was started. The ship veered to the wind a little and enabled the tender to get in some of the slack hose (300 feet had been paid out) and partly clear it. The diver was then called up; and he made the ascent, at least part of it, at a considerable inclination from the vertical.

The wind and sea had increased to such an extent that diving from a sailing launch would have been impossible. The diver arrived on deck in normal condition. Considering the depth of water and the adverse weather conditions, this dive is regarded as a remarkable one.

13. October 29:

A. M.—Sounded over location in vicinity of Plum Gut, indicated on chart as having a depth of 47 fathoms, but could find no water deeper than 25 fathoms.

P. M.—Shifted position to a location off the Race, Long Island Sound, where deep water was found. As slack water had been missed, ran back to New London.

14. October 30:

A. M.—Got underway and stood out to the Race. Weather conditions impossible for diving. Headed for Newport, R. I.

P. M.—Arrived Newport.

15. October 31: Arrived Melville, R. I., and took water and fuel oil on board.

16. November 2: Left Newport and arrived at the Race, Long Island Sound. Weather conditions too severe for continuance of diving operations. Ran into New London for shelter.

17. November 3:

A. M.—Got underway and stood out to diving grounds. Anchored in 45 fathoms. Weather conditions doubtful. Tide and wind from opposite directions, causing a choppy sea. As tide slacked the sea calmed down sufficiently to warrant an attempt at diving. Diver Drellishak was selected to make the dive, the details of which are as follows:

[Depth 274 feet; temperature of water 58° F.; sea moderate; ebb tide 2 knots; weather clear and cool; light breeze.]

Entered water	11.28
Reached bottom	11.35
Called up	11.39½
Left bottom	11.40
Reached 80 feet	11.45
Reached 70 feet	11.48
Reached 60 feet	11.52
Reached 50 feet	11.57
Reached 40 feet	12.03
Reached 30 feet	12.11
Reached 20 feet	12.18
Reached 10 feet	12.28
Left water	1.00

On the descent diver lost a little time getting clear of Jacob's ladder, the bottom rung of which was 80 feet under the water and stopped to descending line. At a depth of about 200 feet diver telephoned for more air. Pressure on surface gauge raised from 150 pounds per square inch to about 175 pounds per square inch. Diver's descent was halted when he signaled for more air and he was started slowly towards the surface. At end of about 3 minutes he telephoned "O. K." and "lower," "air all right," and then descended rapidly to the descending line weight, which he found off the bottom. Diver and weight lowered to bottom. Diver reported that when he neared bottom the tide suddenly became very strong. Diver moved around on bottom and collected a quantity of pebbles and a small rock covered with coral growth.

On account of the treacherous currents at the Race and the unreliability of the strength of the ship's low-pressure air line, diver was called off the bottom at end of 5 minutes. He made the ascent to the bottom rung on Jacob's ladder (80 feet from surface) steadily and without difficulty. As the depth was greater than any with which we had had any experience, extra time, especially at 10-foot stage, was taken for decompression. Diver arrived on deck in normal condition; no ill effects. The exact location of dive was fixed by cross bearings: Race Rock Light, 81° true, distance 5,575 yards; Little Gull Light, 179° true, distance 3,700 yards. The true depth was ascertained by means of a length of piano wire and a 32-pound lead. The sounding wire was vertical when lead was on bottom. A mark was made at water's edge and the sounding measured with a steel tape line as the sounding wire was reeled in. This sounding was carefully checked by several soundings with a special hand lead (32 pounds) line. Soundings taken by Ensign F. M. Collier, United States Navy, assisted by ship's quartermasters and under the personal direction of the commanding officer, Lieut (J. G.) L. F. Thibault, United States Navy. Bottom was hard and covered with gravel. The time occupied by diver in actually descending was 2 minutes. The total time diver was in depths over 100 feet was approximately 15 minutes.

Total time of descent, 7 minutes.

Total time on bottom, 5 minutes.

Total time of ascent, 1 hour 20 minutes.

Total time under water, 1 hour 32 minutes.

Air pressure corresponding to the depth of 274 feet was 8.3 atmospheres (121 pounds per square inch) excess pressure by gauge or 9.3 atmospheres (135.7 pounds per square inch) absolute.

The exact depth of water was 273 feet 10½ inches.

Descending line 3-inch manila rope.

Descending weight 332 pounds.

Due to effects of tide descending line weight kept lifting off bottom. While diver was down ship kept yawing through an arc of about 16°. Reducing valve on low pressure air line was set to operate at 170 pounds pressure at commencement of dive and later changed to operate at 200 pounds pressure. The drop in pressure at diving hose connection at first setting of reducing valve was 20 pounds. At second setting of reducing valve the drop was 25 pounds. The loss in delivery of air at the diver's helmet, due to friction in the air line and hose, was considerable. It is estimated that the air pressure at the diver's control valve was less than 30 pounds in excess of the water pressure at 274 feet. The volume of free air passing through the helmet at 274 feet is estimated to have been 40 cubic feet per minute (more than the capacity of the ship's torpedo air compressor).

Previous to the descent the precaution had been taken to connect two fully charged torpedo air flasks to the air line in addition to the torpedo air compressor. These flasks have a capacity of 11 cubic feet each at 2,100 pounds pressure per square inch. During the dive the pressure in the two flasks dropped 500 pounds. On the ascent when the diver reached shallower water the pressure in the flasks again commenced to gain and before the diver left the water was once more at 2,100 pounds. The air compressor was then stopped and air supplied from the flasks.

All signals to diver were by telephone. The diver estimates that he lost the sunlight and passed into darkness at about 150 feet from the surface and reported that the only discomfort he experienced during the dive was due to warm air, and that was not excessive.

18. On account of the conditions mentioned in the foregoing and in consequence of the probable delays to be expected from bad weather at this season of the year and as the purpose of the tests had been accomplished, it was decided to conclude the tests. Divers Crilley and Nielson begged for an opportunity to equal Drellishak's dive, and no doubt is entertained but what they could have done so with equal facility, if not more so. For the reasons given it was inadvisable to proceed further at this time.

19. The complete details of the information gained as a result of these tests will be included in the final report of the deep-diving tests which will be forwarded to the commandant as soon as possible. In general, however, the conclusions derived as a result of the long series of diving tests and experiments just completed, may be briefly stated as follows:

(*a*) Deep diving is a practical procedure and not attended by great dangers when the proper precautions are observed.

(*b*) The method of furnishing air to divers in deep water by manually operated diving air pumps presents many difficulties and is impracticable under ordinary service conditions.

(*c*) The method of supplying air to divers from power-driven compressors, as developed during the deep-diving tests is efficient, safe, and practicable under all conditions.

NOTE.—About 100 dives have been made by this method in depths of water ranging from 10 to 274 feet and in pressures corresponding to these and intermediate depths. In no case was the slightest difficulty experienced with the supply or control of air to the divers (many of whom were inexperienced). Analysis of the helmet air under various conditions points decidedly in favor of this method. The divers who have tried both methods are unanimously in favor of diving with air from power-driven compressors in preference to the ordinary diving pumps.

20. It will be noted from the records of dives included in this report that there were no mishaps; that dives were made under severe conditions; that the ordinary diver's signals were dispensed with; that all communication to and from divers was by telephone; that in all but the last dive the life line was dispensed with; that several dives were made while using air direct from torpedo air flasks; that the diver controlled his own air supply; and that all dives were made in the ordinary navy apparatus.

21. During the course of deep-diving tests an improved diving apparatus has been developed that will add much to the efficiency of divers; improved methods of diving have been perfected; and, so far as is known, every diving record has been surpassed, including those for speed in descending, depth of submergence, and length of exposures to high pressures. A few of the records made are as follows:

Depth 274 feet. Speed in undergoing air pressure, 90 pounds excess pressure in 40 seconds. Speed in descending under water 136½ feet in 1 minute. Subjection to air pressure 1 hour at 75 pounds, ¾ hour at 90 pounds, ½ hour at 100 pounds, ¼ hour at 110 pounds, and $\frac{1}{12}$ hour at 121 pounds excess pressure. We have no evidence, experimental or otherwise, upon which to base an opinion as to the maximum depth to which a diver might descend for a limited time without danger from oxygen poisoning; however it is safe to assume that a diver could reach a depth of 300 feet or a little more and remain with safety for a short period of time. If the operations were conducted from a submerged vessel the hampering effects of surface conditions would be avoided; shorter lines could be used; and the effects of tidal currents would be minimized.

22. Much valuable information in regard to the physics and mechanics of diving and for the avoidance or overcoming of accidents have been obtained. The complete information will be forwarded with the final report.

23. When they can be printed a set of photographs will be forwarded in connection with this report. (*Note—See following pages.*)

G. D. STILLSON.

[First indorsement.]

NOVEMBER 6, 1914.

From: Construction Officer.
To: Industrial Manager.
1. Forwarded.

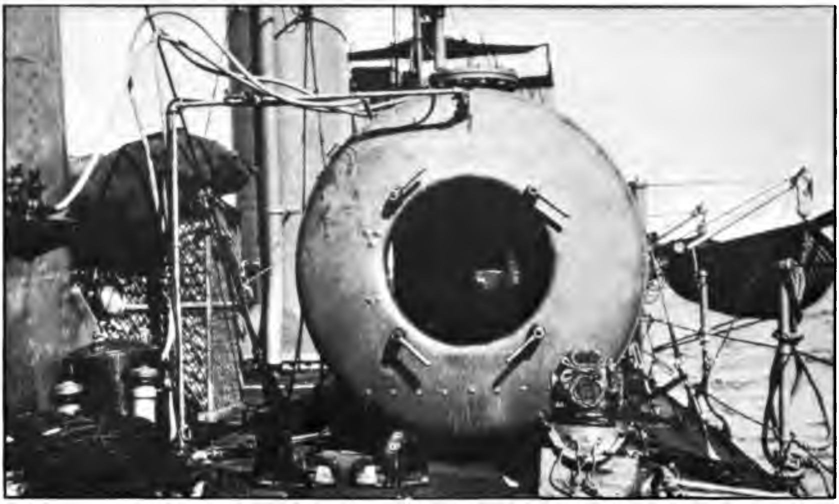
STOCKER.

[Second indorsement.]

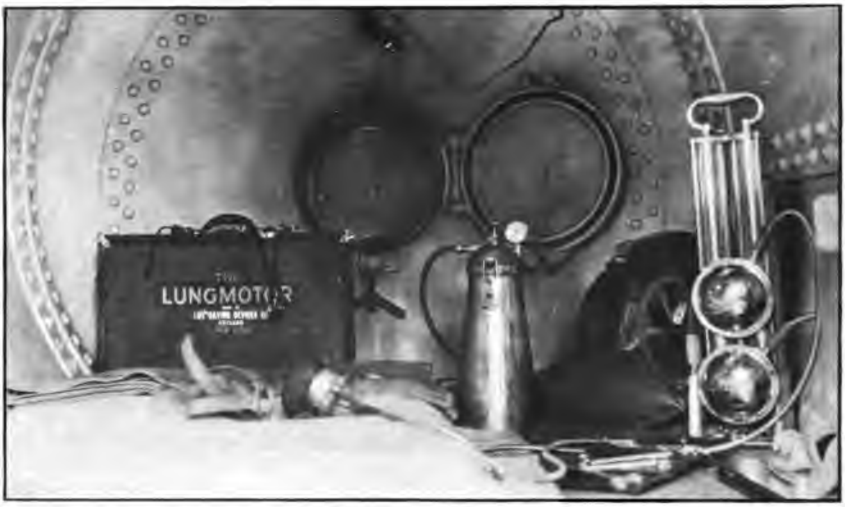
NAVY YARD, NEW YORK,
November 9, 1914.

From: Industrial Manager.
To: Bureau of Construction and Repair.
1. Forwarded.

G. E. BURD.

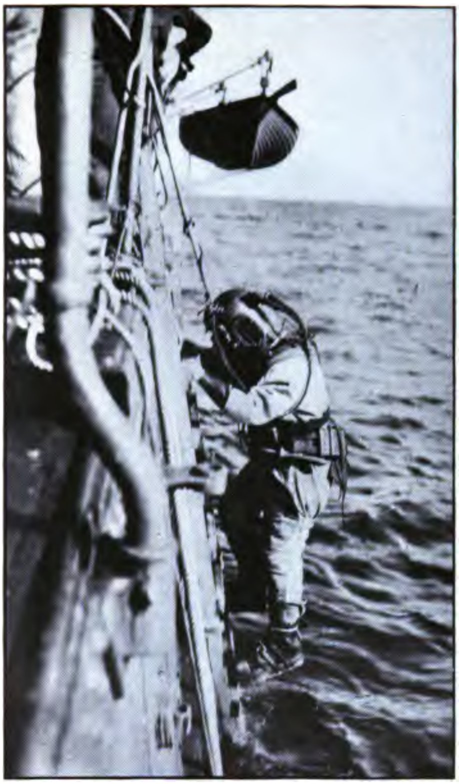


No. 1. U. S. S. Walke. Recompression chamber deep-diving tests October 21 to November 5, 1914.

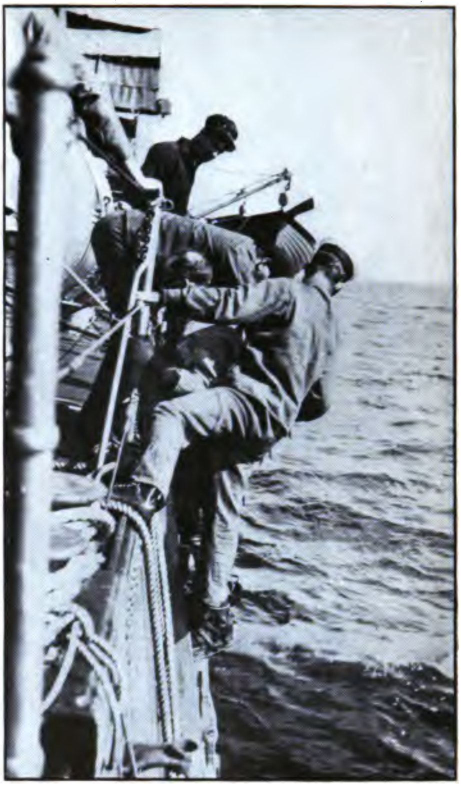


No. 2. U. S. S. Walke. Interior of recompression chamber.

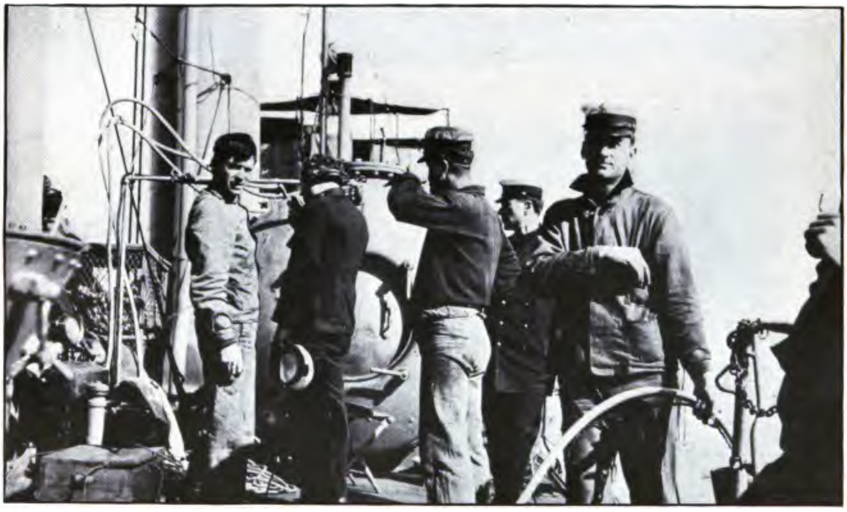
No. 3. U. S. S. Walke. Diver Stillson dressing.



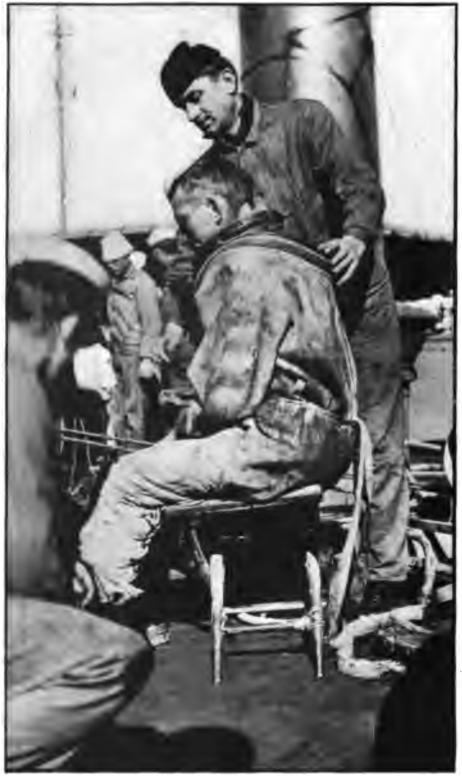
No. 4. U. S. S. Walke. Diver Stillson descending, depth 90 feet.



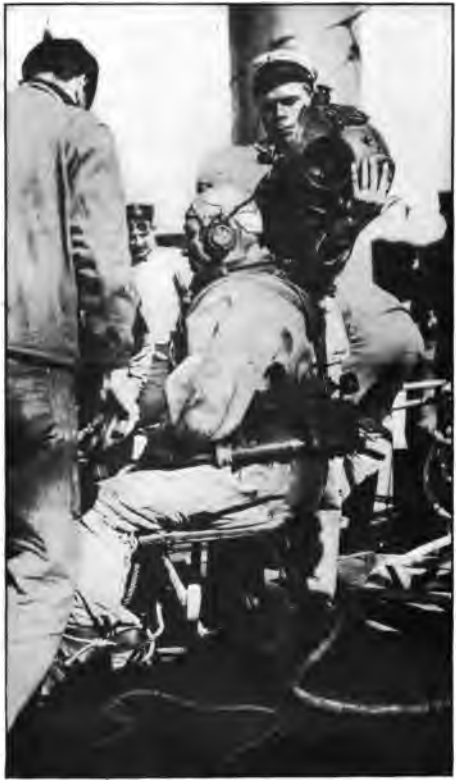
No. 6. U. S. S. Walke. Diver Stillson on ladder. Attendants removing weighted belt.



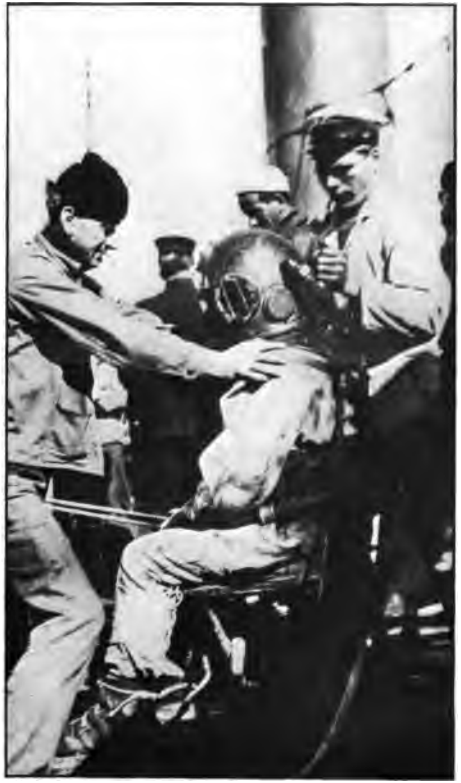
No. 5. U. S. S. Walke. Diver Stillson on bottom. Passed Asst. Surg. G. R. W. French talking to diver by telephone.



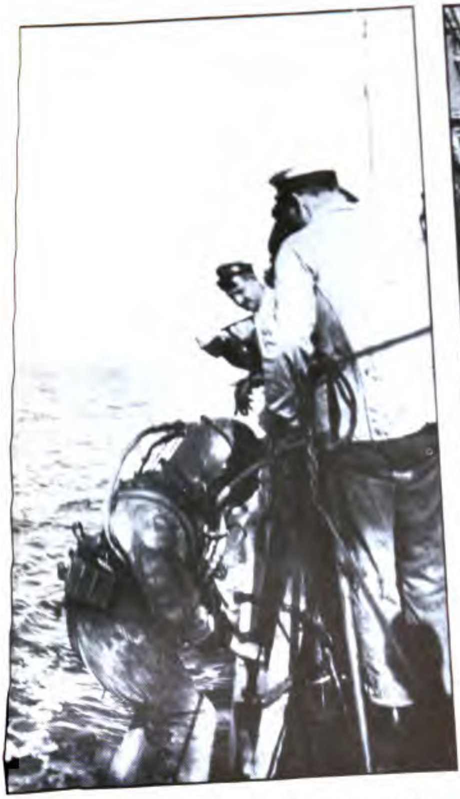
No. 7. U. S. S. Walke. Diver Drellishak preparing for a descent in 45 fathoms.



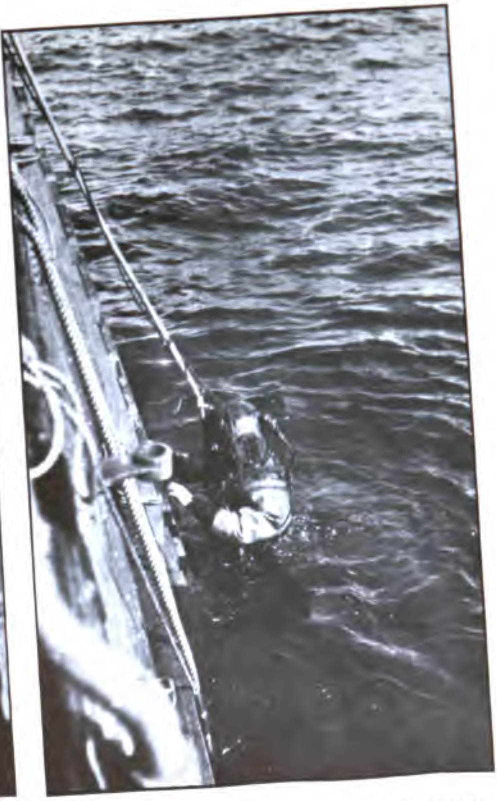
No. 8. U. S. S. Walke. Diver Drellishak putting on the helmet. Note the telephone head set on diver's head.



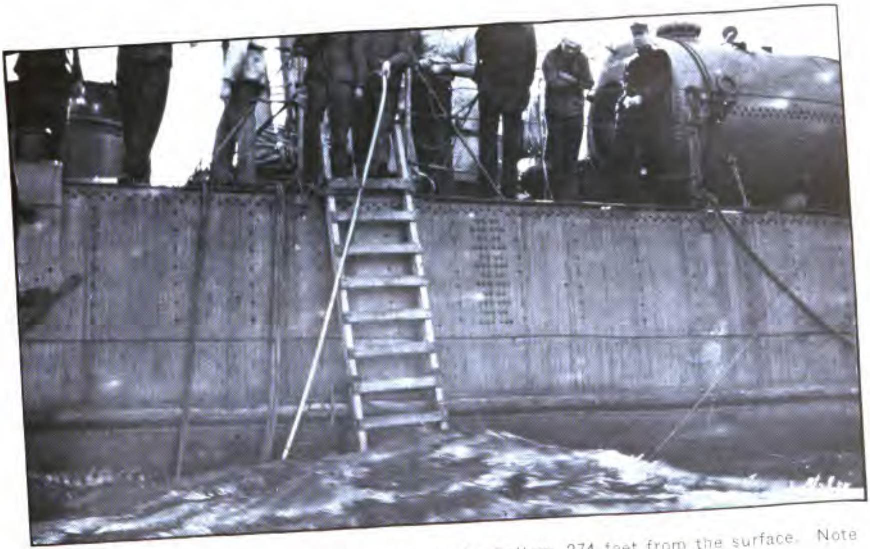
No. 9. U. S. S. Walke. Diver Drellishak. Final adjustments to apparatus.



No. 10. U. S. S. Walke. Diver Drellishak descending.

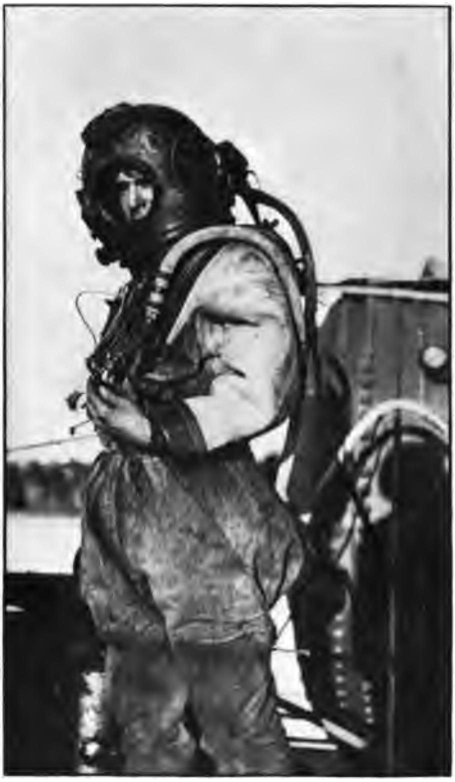


No. 12. U. S. S. Walke. Diver Drellishak ascending unassisted from 10-foot stage. Ascent from 274 feet occupied 1 hour 20 minutes.

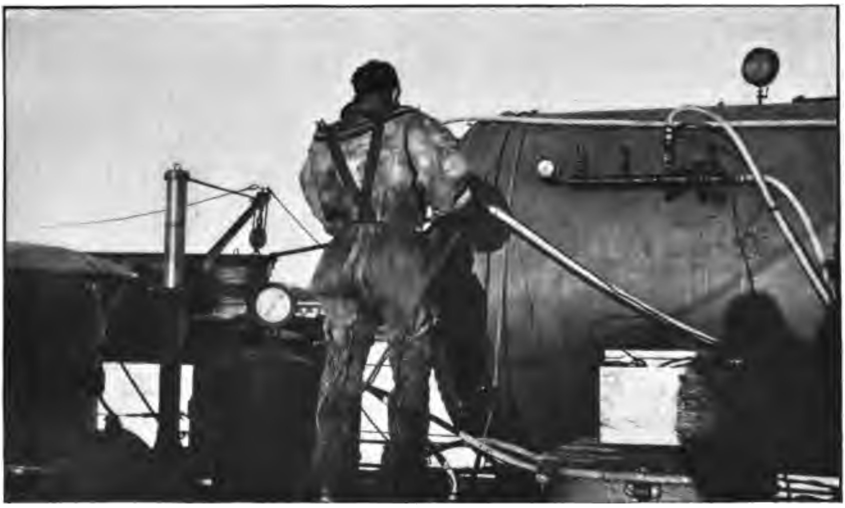


No. 11. U. S. S. Walke. Diver Drellishak on the bottom 274 feet from the surface. Note rough sea, overboard rig, etc.

No. 13. U. S. S. Walke. Diver Drellishak (chief gunner's mate, U. S. N.). Photograph taken immediately after his arrival on deck from a 274-foot dive.

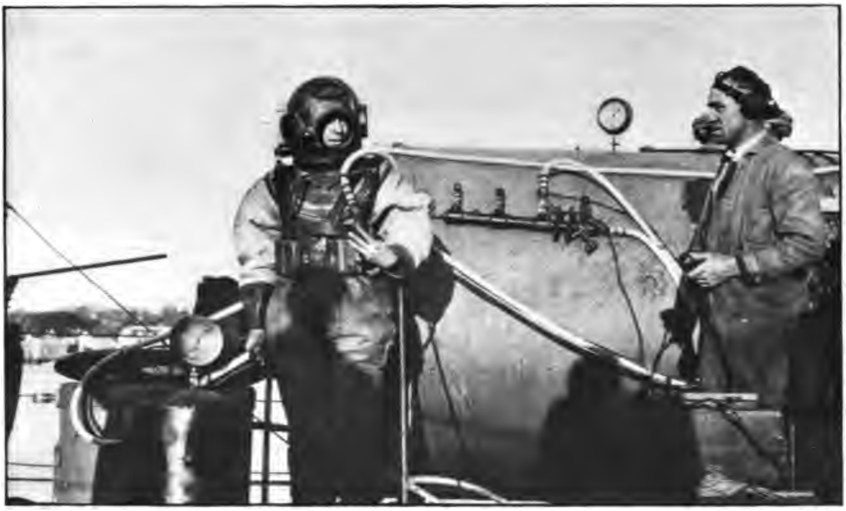


No. 15. U. S. S. Walke. Diver Crilley showing air-control valve in place.



No. 14. U. S. S. Walke. Diver Crilley showing laced canvas overalls. Note diving manifold, test tank, recompression chamber, etc.

No. 16. U. S. S. Walke. Divers Nielson, Crilley, and Drellishak.



No. 17. U. S. S. Walke. Diver Crilley showing location of air-control valve.

APPENDIX 2.

No. E-8.]

JANUARY 23, 1915.

From: Gunner G. D. Stillson, United States Navy.
To: Industrial Manager.
Via: Construction Officer.
Subject: Submarine escape apparatus, report of tests on.
References: (*a*) Bu. C. & R. letter, Jan. 22–14, No. 957–A. 170 (2/19); (*b*) Con. Off. letter, Jan. 27–14, No. 1100–A; (*c*) Bu. C. & R. letter, July 6–14, No. 957–A. 168–S–8/1; (*d*) Gunner Stillson's letter, July 23–14, No. E–2; (*e*) Bu. C. & R. letter, Aug. 8–14, No. 957–A. 168–S 9/1; (*f*) Bu. C. & R. letter, Dec. 2–14, No. 957–A. 168–S 12/29; (*g*) Con. Off. letter, Dec. 9–14, No. 1113–A.; (*h*) Gunner Stillson's letter, Dec. 10–14, No. 67–T.
Inclosure: (6) Photographs.

1. Attention is invited to the reference (*d*) above, which will serve as a preface to this report. I may supplement the reference quoted by a brief resumé of the experience with submarine escape apparatus to date.

2. Previous tests and trials with various apparatus and appliances have proven unsatisfactory for several reasons, the details of which are recorded in the files of the bureau.

3. Some time ago the Electric Boat Co. introduced an apparatus for the purpose outlined, and 20 sets were given an extensive trial. The final result was that the entire lot found their way to the scrap heap.

4. The failure of these particular apparatuses is ascribed to have been due to lack of experience, improper training, fear of the conditions of training, and to the awkward dimensions of the apparatus.

5. The apparatus, though of a limited capacity, was quite similar to the one recently tested, and many of the adverse criticisms were not based on accurate knowledge nor were the trials carefully and scientifically conducted. In other words, an opportunity was neglected during which an efficient submarine escape apparatus could have been developed.

6. The submarine escape apparatus, as submitted by Siebe, Gorman & Co., of London, England, has been tested and found efficient, but not entirely suitable for existing requirements.

7. With certain modifications, to be described, it is believed that this apparatus will adequately dispose of the problem of providing a means which will enable the crew of a sunken or disabled submarine boat to escape and ascend safely to the surface from any depth of water in which an accident might be expected to occur, and to remain afloat at the surface for an indefinite period of time.

8. The objectionable features of this apparatus are as follows:

(*a*) It is too cumbersome and requires too much space for stowage.

(*b*) It does not possess within itself the means for balancing the pressure of water at other than shallow depths.

(*c*) The nose clip provided for closing the air passages through the nostrils is awkward and not efficient.

(*d*) The arrangement of air cylinders and their tubes and valves is not satisfactory.

(*e*) The relief valve opening is too small in diameter to permit the proper control of excess buoyancy.

(*f*) The jacket is not perfect in the details of its dimensions.

9. These features, while undesirable, can not be properly termed as defects in design or construction, for under other conditions than those to be encountered in a consideration of the problems of escape from the particular types of submarines in the Navy, the apparatus is very efficient.

10. The modifications necessary to suit the peculiar conditions and requirements of the submarine service can be accomplished by the manufacturers, and it is recommended that the points outlined be taken up with them.

11. Referring to the photograph showing the apparatus assembled for stowage, it will be seen that it would be impracticable to stow an individual apparatus for each member of the crew on board a submarine of any type now in service. By changing the form and construction of the helmet and the size and arrangement of the air cylinders it will be possible to correct this feature entirely and to provide an apparatus equally as efficient and one that can be made up in neat form for stowage. A consideration that must not be lost sight of is the fact that the apparatus must always be ready for instant use.

12. When the wearer goes under water, the water rises within the jacket and compresses the confined air up into the helmet. The deeper the submergence the smaller the air space becomes and it is plain that the depth at which it can be safely used is thus limited. To extend its range of usefulness, compressed air from the largest cylinder, shown in the photograph, is admitted to the interior of the helmet. The admission of an extra amount of air forces the water to a lower level and permits the wearer to reach a greater depth. By actual trial at diving the maximum depth attainable with the apparatus, as shown, was about 80 feet.

13. When used as a diving apparatus the diver can suit himself as to depth or pressure in which he may go. In other words, if he finds the water in the dress rising to a higher level than is safe, he can stop the descent, when the water level will remain constant, providing the helmet does not leak.

14. When used as a submarine escape apparatus the pressure of water is irresistible and the man and his apparatus must accommodate themselves to the depth or pressure they may find. This operation may have to be done quickly, in darkness, and under the stress of excitement.

15. Assuming it were necessary to escape from a disabled and sunken submarine, three conditions are to be carefully considered:

First, the boat may rapidly fill with water and there may be no air space left within the structure, certainly not enough to accommodate a whole crew. Under this condition, the supply of compressed air within the apparatus must be sufficient to overcome the water pressure or the man will drown. Thus, with the apparatus submitted, a man's chance for life would be hopeless in a depth greater than 75 or 80 feet.

Second, a certain amount of water may enter the boat but still leave confined air spaces where the crew could live until the pressures within and without the boat were equalized. In this case they could put on the apparatus, enter the air spaces, and keep their helmet windows opened until the air and water pressures were equalized. Then when it became necessary to enter the water, the water level in the helmets would be exactly right and escape could be accomplished without difficulty.

Third, if, under the above conditions, the electric storage batteries should give off chlorine gas and contaminate the air spaces, the helmet windows would have to be closed immediately and the condition of the men would be precisely the same as in the first case.

16. The apparatus does not provide for the first and third conditions mentioned in the preceding paragraph. If these are the conditions to be reckoned with, then the only solution is an increased air supply. In providing an increased air supply from cylinders attached to the apparatus the question of stowage must be given consider-

ation. A special flexible connection in such a manner as to permit neat stowage and to be detachable after serving its purpose is strongly recommended.

17. A small spring wire nose clip in place of the present one would be satisfactory. It would not come off while putting on the dress and would not be knocked off by coming in contact with the helmet.

18. When properly adjusted the apparatus has small negative buoyancy under water. When the ascent to the surface is started the contained air is expanded due to the diminished pressure and unless it is partly exhausted the speed of ascent will be accelerated to a dangerous velocity. The present relief valve will exhaust air only very slowly and, necessarily, to ascend safely the operation must be performed very slowly on account of this valve. Ascending with a slow operating valve is dangerous because the buoyancy must be kept nearly neutral in order to keep control of the apparatus. With a larger valve greater positive bouyancy can be controlled more readily and easily.

19. The jacket can be made to fit better and, also, a little smaller, thus decreasing the stowage dimensions, which is an important consideration.

20. With the modifications suggested, an apparatus of the same general type but of smaller dimensions will be provided and, also, one that will meet every required condition. To accomplish this result a certain amount of experimental work will be necessary in order to produce a finished article.

21. In an effort to determine the value of the apparatus to the Navy, and to accomplish this result at minimum cost, the tests were limited to practical trials under water. No effort was made to determine scientifically the probable cause and extent of the chemical processes occurring in the apparatus nor to study the physiological effects that might be expected to occur from its extensive use in service.

22. The apparatus was found to operate very efficiently, with the exceptions to be noted, but as it was seen that certain modifications would have to be made and that the improved apparatus would also need to be carefully tested, the conclusion was reached that the necessary scientific data could be acquired more advantageously at that time than during the present series of tests. For these reasons the tests were concluded.

23. To determine the duration of time the apparatus would sustain a man under water on one charge of "oxylithe" the following tests were made:

Diver.	Time under water.	Pressure of water per sq. in.	Equivalent depth of sea water.
	Minutes.	*Pounds.*	*Feet.*
Drellishak	35	1	2
Crilley	26	15	33
Nielson	53	30	67
Drellishak	52	45	101
Do	70	45	101
Crilley	35	88	198

24. In the first three tests, it was the first time any of the men ever had the apparatus on and some time was lost in experimenting and getting used to the gear. In all the tests the divers were called up out of the water before the limit of endurance was reached. It has been definitely determined that the apparatus will furnish respirable air, to any man doing light work, continuously for one hour with a considerable factor of safety.

25. In remaining at high pressures it was necessary to consider the principles of diving and in every case decompression was ordered before it was necessary to do so on account of the apparatus.

26. To determine the pressure of water or air a man wearing the apparatus could stand to have forced upon him the following tests were made:

Diver.	Pressure of water applied per sq. in.	Equivalent depth of sea water.	Time under water.
	Pounds.	*Feet.*	*Minutes.*
Crilley	32	70	30
Do	88	198	30
Nielson	95	213	10
Grilley	98	219	20

27. The periods under water were limited only by the necessities of decompression. In the first dive the depth reached was limited by the capacity of the air supply in the bottle furnished by the manufacturers.

28. To determine whether or not it would be possible to dive to great depths with a proper air supply, a special cylinder containing an increased supply of compressed air at high pressure was fitted; the results were as indicated.

29. To determine what the effects of work on the diver would be, diver Drellishak made a dive under water at 30 pounds pressure (67 feet) and performed strenuous work continuously for 30 mintues, when he was called up for an examination. He was in normal physical condition and stated that he felt no distress whatever. Buoyancy and other tests were made and with excellent results.

30. Previous to the tests, the possibility of dangerous alterations occurring in the composition of the air contained in the helmet at high pressures was greatly feared, and oxygen troubles were confidently expected. Adequate chemical apparatus was not available for making analysis of the helmet air, but, so far as the effects on the divers gave evidence, the functioning of the oxygen generator and the absorption of carbonic acid gas were perfect. The dangers alluded to, and met with in similar types of apparatus in which oxygen is furnished from metal cylinders, have been eliminated.

31. When using oxygen from metal cylinders it can not be supplied exactly at the same rate a man would breathe it, due to his varying requirements, and for which reason there results either an excessive supply or a deficiency of oxygen. As applied to diving apparatus either condition is dangerous.

32. The remarkable feature of the compound "oxylithe" is that, due to the construction of the apparatus in which it is used, it gives off oxygen only in the volume in which it is required. For this important reason the contained air in the helmet remains constant in volume and in composition. At least, it produces no untoward effect upon the divers at great depths and under varying conditions of temperature, work, and pressure.

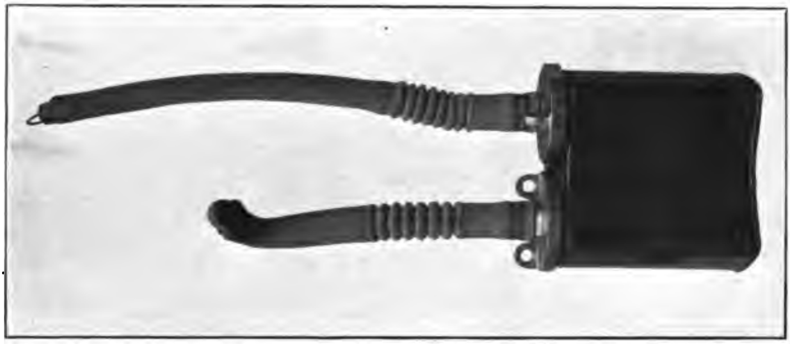
33. The Siebe-Gorman apparatus, except for the details mentioned as objectionable, due to special requirements, is very efficient as an escape apparatus, and is recommended for favorable consideration.

34. It is further recommended that the improvements mentioned be made and that careful and scientific tests be made to determine the capacity of the apparatus in every particular.

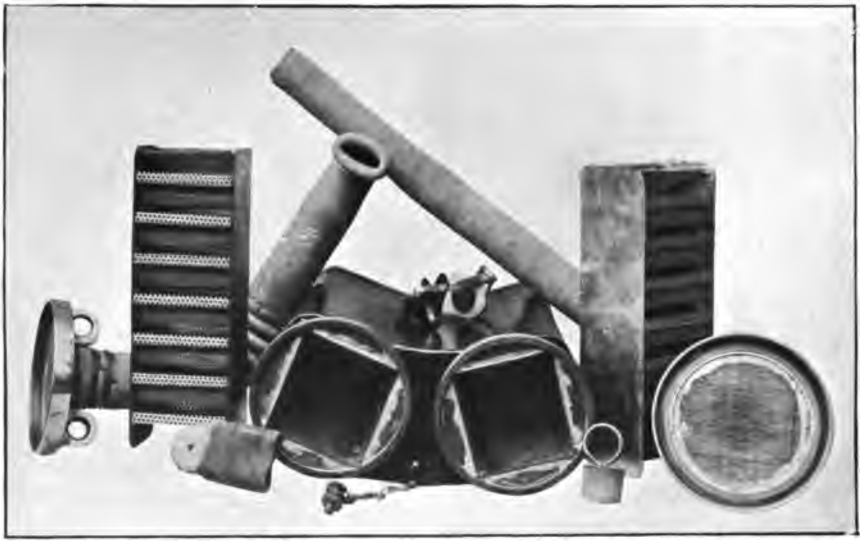
35. Details of the proposed improvements will have to be determined experimentally. These can be accomplished by a process of trial and elimination, keeping in mind, at the time, all requirements of possible service to which the apparatus may be subjected.

G. D. STILLSON.

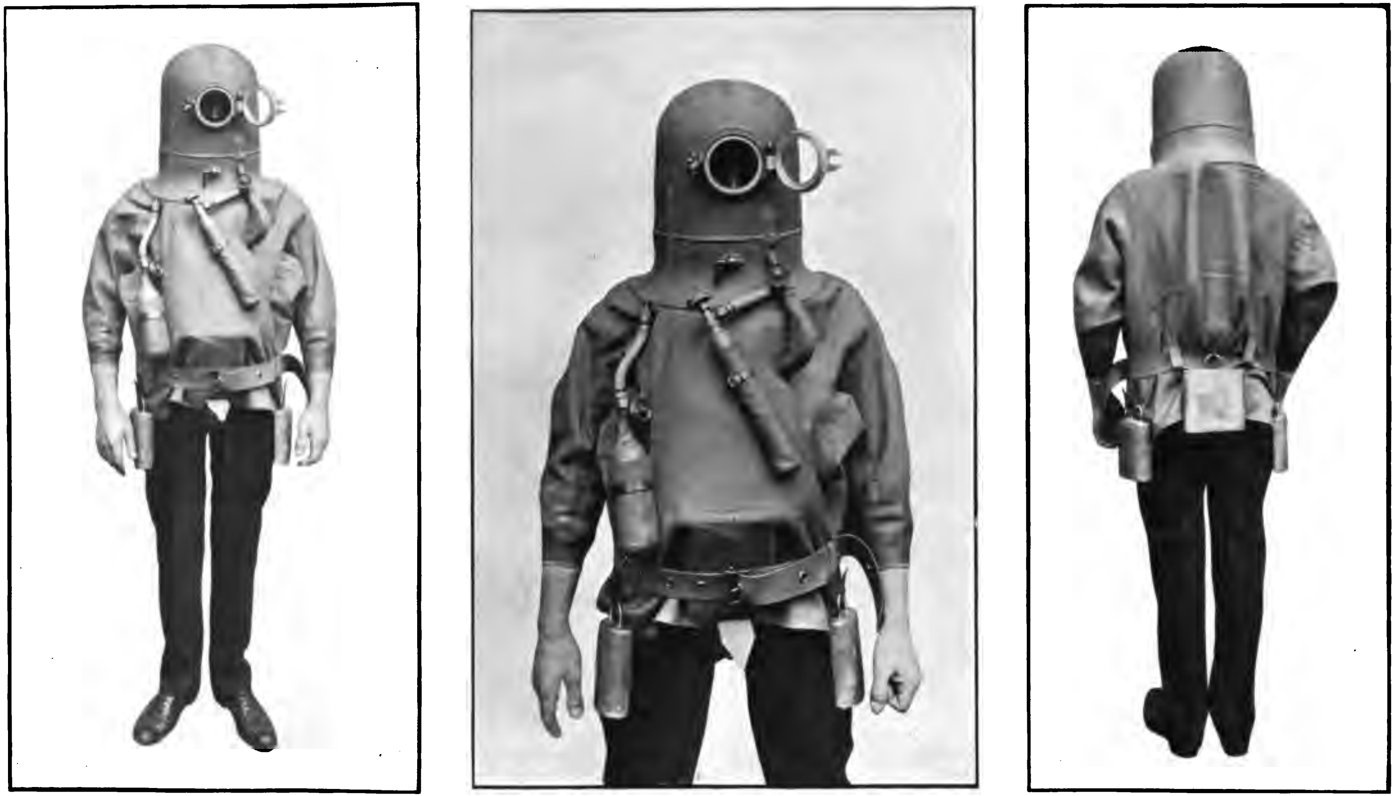
Siebe-Gorman submarine escape apparatus. Navy yard, New York, December 19, 1914.



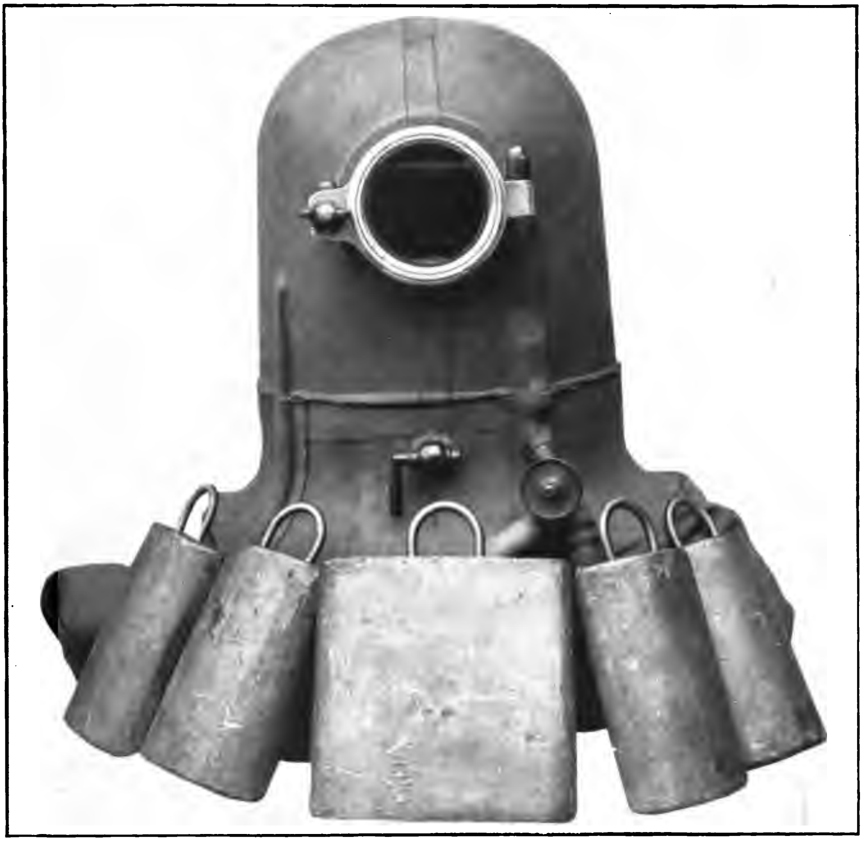
View of oxygen generator.



Oxygen generator disassembled.



Siebe-Gorman submarine escape apparatus. Navy yard, New York, December 19, 1914.



Siebe-Gorman submarine escape apparatus, assembled for stowage. Navy yard, New York, December 19, 1914.

231–3

[First indorsement.]

JANUARY 25, 1915.

From: Construction Officer.
To: Industrial Manager.
Subject: Submarine escape apparatus, report of tests on.

1. Forwarded.

STOCKER.

[Second indorsement.]

NAVY YARD, NEW YORK,
January 27, 1915.

From: Industrial Manager.
To: Bureau of Construction and Repair.

1. Forwarded.

G. E. BURD.

[Third indorsement.]

FEBRUARY 3, 1915.

From: Bureau of Construction and Repair.
To: Navy Department (Material).
Subject: Siebe-Gorman submarine escape apparatus, report of tests on (C. & R. letter Jan. 23, 1915, 15717-A1-S).

1. The within report covers the test of the Siebe-Gorman submarine escape apparatus, referred to in paragraph 3 of this bureau's letter referenced above.

2. It appears from this report that the apparatus in question is the most promising of any form of submarine apparatus tested so far.

3. The bureau has taken up with the manufacturers the question of having the changes recommended in this report made in the apparatus and that a modified apparatus be made for test. Upon receipt of further information regarding this matter further recommendation will be made as to the type of escape apparatus considered most desirable for use on submarines.

4. Return of papers requested.

TAYLOR.

FEBRUARY 9, 1915.

Navy Department (Division of Material).
Forwarded to the Bureau of Construction and Repair.

APPENDIX 3.

OBSERVATIONS ON DEEP DIVING.

By G. R. W. FRENCH, Passed Assistant Surgeon, United States Navy.

In order to comprehend deep diving a knowledge of the diving apparatus is essential. The parts of the diving apparatus are as follows:

1. The dress.
2. Breastplate.
3. Helmet with various valves, etc
4. Diving hose.
5. Pumps.
6. Weights (belt and shoes).
7. Telephone.
8. Life line.
9. Diving gloves.
10. Overall dress.

The dress is of flexible material made of sheets of rubber between cotton twill and reinforced at the points of wear. It is so constructed that it incloses the entire body with the exception of the head and hands.

The sleeves of the dress terminate in an elastic cuff which forms traxit joint at the wrist and prevents the escape of air or the inlet of water under normal conditions.

The neck of the dress terminates in a rubber gasket, or collar, with an inside portion of cloth called the bib. The purpose of the collar is to attach the breastplate to the suit, the breastplate fitting between the rubber collar and the bib. The bib fits loosely and comes well up inside of the neck piece of the breastplate. The object of the bib is to collect any water that may enter the helmet through the valves and prevent this water from coming in contact with the diver's body. The function of the dress is simply protective, protecting the divers' body from wet and cold.

It is considered that the present type of diving dress in use in the Navy is defective in design and the following improvements are recommended:

1. Increasing the length of the body of the dress, i. e., length between the crotch and collar to allow more freedom of motion in bending (flexing the trunk).

2. Increasing the length of the arms to allow more freedom of motion in reaching overhead, as in climbing.

3. Adopting a diving suit with laced legs. This is most important for the following reasons: In the present type of suit the legs are large and baggy and allow considerable space for air accumulation. If for any reason air accumulates in the legs of the present type of suit, as is often the case with the diver working in a prone condition, the legs become more buoyant than the head, which causes the diver to lose control of himself usually resulting in the diver being "blown up," i. e., carried rapidly to the surface either feet first or in a prone position, and helpless. In the improved type of suit with the laced legs this danger is eradicated, as the legs are laced snugly to the body and there is no space in the legs of the suit for air accumulation.

Formerly crinoline was worn inside of the dress with the idea that it was a protection from outside pressure. This is a false idea. The use of crinoline is dangerous. It is useless and encumbering and should be discarded as a useless piece of apparatus.

The breastplate is that portion of the diving apparatus which connects on the lower end with the dress and on the upper end with the helmet. It is of tinned copper and so made that the lower portion fits comfortably over the shoulders, a pad usually being interposed between the shoulders and the breastplate. Its upper end is circular and comes on a level with the larynx.

The breastplate is attached to the dress by means of screw studs which pass through holes in the rubber collar. Four metal straps conforming with the curvature of the breastplate are placed over these studs and held in place by wing nuts. When these nuts are screwed down the collar of the breastplate is compressed between the straps and edge of the breastplate, thus forming an air-tight joint.

It is considered that the Navy breastplate is too wide and it has been recommended that the breastplate be made narrower to allow more freedom of motion in reaching upward.

The helmet is attached to the circular ring at the neck of the breastplate by an interrupted screw joint in the most improved models. A small stop, or pin, is provided at the back of the helmet which is turned down into a recess on the breastplate as a precaution against the helmet screwing off.

The helmet is a tinned copper dome which incloses the diver's head, fitting tightly to the circular neck of the breastplate by means of an interrupted screw joint. A gasket is interposed at the joint between the helmet and breastplate, making an air-tight joint. The helmet is constructed with four windows. One is directly in front of the diver's face, called the faceplate. It is the last piece of the helmet to be applied and is usually adjusted while on the ladder just before the diver makes his descent. The other three windows are made in the helmet and are not removable, being glazed in. Two are placed one on each side of the helmet, on a level with the faceplate, so as to enable the diver to see laterally. The fourth is placed in the mid line of the helmet above the faceplate, and permits the diver to look upward.

The air-inlet valve is placed on the back part of the helmet above the interrupted screw joint. This valve is a nonreturn valve, or check valve, and its proper functioning is most important. The check valve should be capable of standing a back pressure considerably more (500 pounds to the square inch) than the pressure at which the diver is to work. Air enters through this valve into the helmet, and it should be capable of admitting air at a pressure of 1 pound to the square inch. The nonreturn function of the inlet valve is most important for the reason that if the pressure supplying air to the diver were to fall appreciably or suddenly on any account, as for instance, a ruptured hose, the result would be an immediate squeeze to the diver, and if working at any depth beyond 10 feet results are liable to be serious. If the depth at which the diver is working is beyond 15 feet the results are apt to be fatal.

The regulating escape valve is fitted into the right side of the helmet in the rear of the side window and at about the level of the ear in the present types in use in the Navy. The valve seats with the water pressure and against the air pressure within the dress. An excess of air over water causes the air to escape into the surrounding water. The valve is provided with a spring and regulating screw on the water side by means of which the diver can regulate the inflation of his dress, and, thus, his buoyancy. Setting up on the regulating screw compresses the spring and applies tension on the valve, in addition to the water pressure, and an increased pressure of air is necessary to open the valve. The improper adjustment of this valve is the cause of a most vicious trend of circumstances to the diver. As a diver enters the water pressure is applied to the outside of his dress and tends to force the air into the upper portion of the dress and out the valve. Setting up on the regulating screw retards this escape in proportion to the tension of the regulating spring. If freely open the air supply is inadequate, the dress will collapse, and the diver's breathing will be interfered with. If partly closed and the air supply is of sufficient volume, too great an inflation of the dress will result and will be followed by an excess of positive buoyancy. Overinflation is the cause of "blowing up" of a diver, which is a serious accident if from any considerable depth.

There are various types of regulating escape valves. The ones in most common use are the Morse, the Schrader, and the Siebe-Gorman.

A serious fault in these escape valves now in use is that they can not be entirely closed. If means of entirely closing were provided, it would be possible for a diver to ascend from any depth without assistance from the surface. The present location of the valve is determined by the construction of the helmet, and it is not accessible to all divers. It should be brought farther forward and down near the junction of the helmet and breastplate in order to be more readily reached by the diver and to maintain a more equal pressure of the air within the air passages and the water without on a minimum air supply with the diver in the erect position.

A new type of air-escape valve has been designed by G. D. Stillson, gunner, United States Navy, which meets with these requirements. This valve can be completely closed and will not jam. If for any reason a diver wished to ascend on account of a short air supply, by closing this valve completely he will attain positive buoyancy and will be able to ascend readily instead of being forced to struggle up his descending line.

In the latest type of helmet there is an extra valve placed to the right and on a level with the faceplate. This valve is operated by the diver. The object of this spit cock is to allow an escape of air from the suit. If for any reason there is an overaccumulation of air in the suit and the regulating escape valve does not allow sufficient escape, the diver opens this spit cock, allowing the excess air to escape.

The diving hose is 1 inch external diameter and one-half inch internal diameter. It is made up in 50-foot lengths which are coupled together by gun-metal fittings, alternate male and female. Openings through the couplings are three-eighths inch in diameter. When new the hose is capable of withstanding a pressure of 500 pounds to the square inch for 10 minutes.

The diving pumps in the Navy are not standardized as to dimensions, capacity, etc. Those most generally used are two-cylinder, double-acting diving machine air pumps. They are designed to furnish one-fifth of a cubic foot of air per revolution (measured at atmospheric pressure). Provision is made for supplying air to two divers in shallow water and one diver in moderately deep water. The cylinders are surrounded by a tank for holding water. The gages on the case of the pump indicate the pressure of air delivered from each cylinder. The pump is secured in a wooden case and provided with ring bolts for securing and lifting about and hoisting. At present there is no standard pump and the efficiency of every pump varies.

Early in the diving experiments it was found that proper ventilation of the helmet could not practicably be secured by hand-driven air pumps in deep diving, and air from power-driven compressors, i. e., air accumulators, was utilized. In order to use air from air accumulators, some means of controlling the amount of air supplied to the diver was necessary. This was met by interposing an additional valve (the Stillson air-control valve) on the diving hose, close to the helmet. This valve is a needle valve attached to diver's breastplate on the left side and is operated by the diver.

The weights used in diving consist of diving belt and diving shoes, the object of these being to cause negative buoyancy when the diver's suit is inflated with air.

The diving shoes consist of a heavy leather shoe with a heavy lead sole. An improved type of diving shoe was tested and found superior to the old type. This shoe, which is more comfortable than the old type, is made with a wooden inner sole in addition to the lead sole and is fitted with a brass toe cap. The wooden inner sole helps to permanently maintain the shape of the shoe. The brass toe cap not only protects the shoe from wear but also the diver's toes from injury. In addition to the securing strap, eyelets for lacing are provided and are considered essential to prevent the shoe from coming off.

The diving gloves, made of the same material as the diving dress, are attached to the outside of the sleeve of the dress by means of metal rings and clamps provided for the purpose. These are neither useful nor ornamental. They are a source of danger and should be improved. When worn, the diver can not use his fingers to control the valve and apparatus as they become distended with air, and he is unable to functionate his hands.

An overall dress is provided to protect the diving dress from chafe and wear. It is cumbersome and seldom used. Overall trousers with adjustable straps answer the purpose of the above. By means of adjustable straps of suspenders the distance between the helmet and the crotch of the diving dress can be regulated to keep the helmet from receding over the diver's head when the dress is inflated with air. This adjustment is important, but is not generally known or practiced.

The underclothing and socks that the diver wears are of medium weight wool and are for use when working in water of low temperature. It is considered that additional suits of heavier weight wool could be added to the diving outfit, as the present suits are not sufficiently warm for work in very cold water.

The present type of Navy diving telephone consists of a simple receiver and transmitter permanently secured in the helmet and connected in series with the tender's instruments and battery.

This has been found to be absolutely useless for the purpose intended. Ten different types of telephones were tried during the diving test. None of the types with the single receiver were found satisfactory. While it was possible for the diver to communicate with the tender with this type it was impossible for the tender to satisfactorily communicate with the diver, especially with the present type of diving apparatus, on account of the noises in the helmet produced by the pounding of pumps and the escape of air from the helmet.

The problem of the telephone was finally solved by G. D. Stillson, gunner, United State Navy, by using double receivers fitted with large flexible rubber ear pieces which exclude all helmet noises from the diver's ears. Even with the proposed type of telephone the noises in the helmet are audible to the tender, but these do not interfere with communication.

The effects of compressed air on the diver's voice are noted over the telephone. The tone of voice is metallic and very loud.

While the timbre of the voice is lost in moderately deep depths, there is no trouble in understanding the diver in depths to 274 feet, if he speaks in a moderate voice.

In deep diving it is considered that a suitable diving telephone is essential.

For the purpose of raising and lowering the diver to and from the bottom, a 21-thread manila rope is provided. This is furnished in 120 feet lengths and is also used as a signal line. On account of the inefficiency of the present type of telephone the only means of communication with the diver is by signals (pulls) on this line. This method limits the diver to a most elementary set of signals and with any drag on the line, as from tide, these are often interfered with.

With the present method of diving in our Navy there are three lines to the diver, i. e., diving hose, telephone cable, and life line. It was hoped by giving the diver absolute control over his buoyancy (by a sufficient and perfectly controlled air supply) that the use of the life line could be abandoned, thus lessening the drag of tide on the lines This was found inpracticable without interfering with safety.

The most improved type of life line is one which embodies the telephone cable.

PHYSICS OF DIVING.

Atmospheric pressure is that pressure exerted by the atmosphere and is equal (average) to 14.7 pounds to the square inch.

Gauge pressure: The gauges used in diving do not record atmospheric pressure. The zero mark of the gauge corresponds to atmospheric pressure. The pressure read on the gauge is referred to as gauge pressure or excess pressure.

Absolute pressure is that pressure above a perfect vacuum, or absolute pressure is atmospheric pressure plus gauge pressure, or 14.7 plus excess pressure.

Every 33 feet of sea water (depth) or 34 feet of fresh water exert a pressure of one atmosphere. Hence, every foot of sea water (depth) exerts a pressure of $\frac{14.7}{33}$, or 0.44545+ pounds to the square inch. Thus a diver working in a depth of 165 feet of sea water would be working in $\frac{165}{33}$ or five atmospheres of excess pressure or six atmospheres absolute pressure.

When a diver stands erect in the water the pressure exerted on his feet and legs is about 2 pounds per square inch more than that exerted on his head and chest.

A body submerged in sea water is buoyed upward by a vertical upward force that is equal to the weight of the displaced sea water. This pressure equals 64 pounds for each cubic foot of the volume of the submerged body.

On a diving suit distended with air the number of cubic feet of water to be displaced is greater than the combined weight of the suit and helmet and diver. As a result the suit and diver are positively buoyant and the diver is unable to descend.

To overcome this positive buoyancy weights are attached in the form of a leaded belt and leaded shoes, giving the diver negative buoyancy. Only sufficient weight is added, however, to overcome this positive buoyance with the suit moderately distended with air.

If, for any reason, the suit is overdistended with air the diver attains positive buoyance, and if below the surface of the water, he will be carried rapidly to the surface unless he holds to something which will enable him to overcome the positive force of his buoyancy. Being carried to the surface in this manner is known as "blowing up."

Divers working in shallow depths often blow themselves up voluntarily. If this happens from deep depths the results are liable to be serious, and this is an accident to be constantly guarded against with divers working in deep water.

In the old method of diving (pumps), if a diver found himself accumulating too much air in the suit with insufficient escape from the escape valve, by putting his hands over his head and slipping a finger under the cuff and expanding it excess air was allowed to escape. With the new method, i. e., spit cock on helmet and a perfectly controlled air supply from air accumulators, the danger of this accident is lessened.

The composition of air is approximately 20.96 per cent oxygen and 79 per cent nitrogen, carbon dioxid varying from a trace to various percentages in different localities. A standard of 0.04 per cent of CO_2 is considered as the maximum amount that should be present in problems of ventilation of houses, ships, etc.

Air follows the law of gases. According to Boyle's Law the volume of a gas varies inversely as the pressure (absolute). That is, air under six atmospheres pressure would measure one-sixth of its volume measured at atmospheric pressure. Example $\frac{14.7}{6\times14.7}=\frac{1}{6}$.

According to Charles's Law the volume of a gas varies one two-hundred-and-seventy-third of its volume for every variation of 1° Centigrade, volume increasing with rise of temperature and decreasing with fall of temperature.

The variation of volume due to temperature is disregarded in diving. When air is compressed by power compressors it becomes heated. The following table shows the additional rise of temperature for each atmosphere of additional pressure.

Heat produced by compression of dry air without cooling.

Pressure above atmospheric.	Temperature of air.
lbs.	°
0	60.0
14.7	175.8
29.4	255.1
44.1	317.4
58.8	369.4
73.5	414.5
88.2	454.3
102.9	490.6
117.6	523.7
132.3	554.0
205.8	681.0
379.3	781.0

NOTE.—The presence of moisture will increase the results as it increases both the specific heat and the heat conductive capacity.

From the above it is evident that this air must be cooled before being supplied to the diver. In the use of hand-driven pumps on account of the water about the cylinders, and the dissipation of heat on the hose, etc., the air on reaching the diver is sufficiently cool to cause no great discomfort up to depths that have been reached heretofore by the use of hand diving pumps.

In utilizing air from air accumulators it is evident that this air is cooled before reaching the accumulators. Accumulators are charged by power compressors and all power compressors are fitted with an elaborate water-cooling system for the compressed air, so that the danger of supplying air too hot to the diver is practically nil.

With the diver in the usual Navy type of diving suit, i. e., a suit with a compressible dress and a rigid noncompressible helmet it is essential that the following conditions be maintained:

A. The diver must be able to ascend and descend, or stay in water of varying depths, maintaining at all times the air pressure within the suit to a slightly higher pressure than the water without; i. e., suit moderately extended with air.

B. The diver at all times must have perfect control of his buoyancy, i. e., maintain positive, or negative, as he so desires, and be so balanced that he will be able to perform useful work.

C. The minimum circulation of air through the helmet must always equal

$$1.5\times\left[1+\frac{\text{depth in feet of sea water}}{33\text{ (if fresh water, 34)}}\right],$$

or

$$1.5\times\left[1+\frac{\text{number lbs. to sq. in. excess pressure exerted by water}}{14.7}\right],$$

or 1.5 × number of atmospheres absolute pressure, cubic feet (measured at atmospheric pressure) per minute.

NOTE.—With the new method of diving it is recommended that at least two or three times this amount of air be delivered. (See Physiology of Diving.)

When a diver enters the water the increased pressure at his extremities drives the air from the lower portion to the upper portion of his dress, the lower part of the dress being forced up against his body. The diver descending farther into the water regulates his escape valve so that sufficient air is forced out of his suit to cause a negative buoyancy that will permit him to descend. Air forced into the helmet increases the pressure within the suit as the diver descends, causing the pressure within to equalize the water pressure without, and soon a slight increase of the inner pressure forces the air out of the regulating escape valve and causes a ventilation of the helmet.

Suppose a diver working at shallow depths should fall suddenly with no sudden ingress of compressed air into the suit. What would be the results?

The diver is working in a compressible dress and a rigid helmet so constructed that any increase of water pressure over air pressure within the helmet causes the regulating escape valve to seat, therefore no water can enter the helmet. Air is forced from the compressible dress into the noncompressible helmet, volume diminishing with increased pressure. If this volume of air does not fill the helmet and equalize the pressure of the water at the depth to which the diver has fallen, the extra pressure is exerted on the diver's body, tending to drive him into the helmet. The result is a serious injury or immediate death.

Falls from shallow depths to deeper depths are the most fatal, as the relative difference of pressure is greater. That is to say, a diver at the surface in 14.7 pounds pressure to the square inch (absolute) falls into water 33 feet deep, every square inch of his body has an additional pressure of 14.7 pounds, or 29.4 pounds absolute pressure to the square inch, or a proportion of 2 to 1 over the pressure in the helmet. As the body has a surface area of 2,000 square inches, quite a few tons (14.7) pressure are exerted on the diver's body, driving him into the rigid helmet.

Falls from moderate depths to deeper depths are not as serious as falls from shallower depths—i. e., in a fall from surface to 33 feet the relative difference in pressure is 2 to 1, while in a fall from 168 feet to 201 there would be a difference in pressure as 6 : 7 and the result would not be as serious.

To overcome the danger from squeeze a new type of collapsible helmet has been designed by a German. The object is to have the helmet collapse before any dangerous extra pressure is exerted on the diver's body. This type of helmet is not considered as practicable as the usual rigid helmet.

With the newer method of diving—that is, the use of air from air accumulators—the adjustment of air control is so perfect that the danger from falls is greatly minimized. The adjustments are so fine the diver is usually able to prevent a fall by opening his air-control valve widely, thus maintaining a sufficient volume of air within the suit at sufficient pressure to prevent a fall.

The air adjustment with this method is so perfect that the diver can allow himself to sink in the water with no supporting line (this has been done innumerable times in depths to 33 feet) without the slightest squeeze.

The question of air circulation through the helmet will be considered under Physiology of Diving.

PHYSIOLOGY OF DIVING.

In average figures the composition of the air in volume per cent equals—

	Per cent.
Nitrogen	79.00
Oxygen	20.96
Carbon dioxid	.04

Expired air varies in composition with the depth of the expiration and with the composition of the air inspired.

Under normal conditions the expired air contains in volume per cent:

Nitrogen	79 per cent.
Oxygen	16.02 per cent.

	N	O	CO_2
Inspired	79	20.96	0.04
Expired	79	16.02	4.38
		4.94	4.34

That is, expired air loses 4.94 v. p. of O, and gains 4.34 per cent CO_2. The difference in the oxygen absorbed and the CO_2 excreted is explained by the fact that in the physiological process of the body some of the O is absorbed by the body, not only to oxidize carbon but also to combine with some of the hydrogen of the food, and is consequently secreted as water.

The composition of alveolar air can not be accurately determined, but is estimated as follows:

Normal expiration contains 500 c. c. (equal normal breathing). The capacity of the bronchial tree is 140 c. c., and this air may be considered as similar in composition to atmospheric air, i. e., the inspired air. Hence alveolar air constitutes only 360 c. c., or eighteen twenty-fifths of the entire amount. If expired air contains 4.38 per cent CO_2, then alveolar air must contain 4.38 divided by $\frac{18}{25}=6$ per cent.

According to Haldane and Priestley, an average adult man at rest breathes one-fourth cubic foot of air per minute. The volume respired is regulated as follows: At normal atmospheric pressure each person automatically regulates his breathing, so that the alveolar air contains about 5.6 per cent of CO_2 (varying slightly in different individuals, but constant for same individual). If the percentage rises breathing becomes increased to effect compensation; if it falls breathing is diminished or suspended until it again reaches normal. Moderate work increases the CO_2 secreted by the lungs to three or four times, and hard work six to eight times the resting normal amount. The air breathed is consequently increased. If the inspired air contains CO_2, the volume of air breathed is likewise increased in such proportion as, if possible, to keep the alveolar percentage nearly normal. Thus, if inspired air contains 3 per cent CO_2 breathing will be about doubly increased, and moderate work in such air will cause moderate dyspnea. Six per cent causes distress, and 10 per cent a tendency to unconsciousness.

When pressure is abnormal the law just stated does not hold, and it is found that what does remain constant is not the percentage, but the absolute pressure exercised by the CO_2; i. e., $\frac{3\ (\text{per cent } CO_2)}{9\ (\text{atmospheres})}$ or one-third per cent of CO_2 would have the same effect on a diver in 264 feet of sea water as 3 per cent of CO_2 would at atmospheric pressure. The same law has been found to hold in air of two-thirds atmospheric pressure.

It has been found that at rest the average man produces about 0.84 cubic foot of CO_2 an hour (measured atmospheric pressure), or 0.016 cubic foot per minute. Haldane, in his work, found by actual analysis that the diver at rest produced 0.019 cubic foot CO_2 per minute, and with moderate work 0.045 cubic foot per minute (measured under normal conditions). Volume of gas varies inversely as the pressure, hence this volume under moderate work must equal 0.045 divided by atmospheres, absolute pressure.

Owing to the limited capacity of the hand-diving pumps, even in series, the delivery of air was so small that a standard of CO_2 equal to 3 per cent divided by number of atmospheres, absolute pressure, was taken as the maximum amount of CO_2 that should be present in a diver's helmet, instead of the usual 0.04 per cent standard considered in problems of ventilation of houses, ships, etc. It was found that the diver could do fair work at 3 per cent CO_2 divided by number of atmospheres, absolute pressure, and not suffer from the terrible dyspnea usually experienced by men diving to moderately deep depths, as was the case before the investigation of this subject.

Taking this as a standard, the necessary standard of air supply is figured as follows:

D=Delivery cu. ft. per minute air required.
E=No. cu. ft. air expired per minute.
R=Ratio of CO_2 desired.
A. P.=Number of atmospheres absolute pressure.

According to the formula $D=\frac{E}{R}$:

$$D=\frac{0.045}{\text{A. P.}}\text{ divided by }\frac{3}{100\times\text{A. P.}},\text{ or }\frac{0.045}{\text{A. P.}}\times\frac{100\times\text{A. P.}}{3}$$

$$D=\frac{4.5}{3}\text{ or 1.5 cubic feet per minute.}$$

It must be remembered, however, that this 1.5 cubic feet is measured at the pressure to which the dive is made. Measured at atmospheric pressure in a dive made to 264 feet with $\left(\frac{264}{33}\right)$ or 8 atmospheres excess pressure, or 9 absolute, it is evident that the air measured at the surface must equal 9×1.5 cubic feet or minimum delivery of 13.5 cubic feet per minute to maintain a standard of 3 per cent CO_2, corresponding to normal conditions.

Better ventilation than this is imperative for hard, useful work in diving. In our work on experimental diving it was found possible to dive with manually operated pumps to depths attained by the English, but deep diving in this manner was not considered practicable.

It is considered that, owing to the limited capacity of manually operated pumps, while diving to moderate depths with efficient tested pumps is practicable, useful diving to excessive depths is not practicable.

A standard of $\frac{1}{\text{no. atmospheres, abs. pressure}}$ per cent CO_2 was proposed; i. e., 4.5 cubic feet of air per minute measured at the absolute pressure. This was found practicable by utilizing air from accumulators, charged or charging by power-driven compressors. In diving by this method to depths up to 255 feet, corresponding to 8.7 atmospheres, absolute pressure, the largest per cent CO_2 present in any of the analyses was 0.1 per cent. Multiplying this by the number of atmospheres of absolute pressure, this corresponds to a CO_2 pressure of 0.87 per cent of an atmosphere, which is considered excellent helmet ventilation for a diver.

In the diving in the experimental diving tank at A. Schrader's Son, Brooklyn, N. Y., the descending air (air used to apply pressure to the surface of the water) and the air utilized to ventilate the diver's helmet were both taken from the same accumulators. These were two large accumulators of low pressure (135 pounds gauge).

Air pressure in the accumulators was maintained by two large-capacity, low-pressure, electrically driven and automatically controlled power compressors (running when pressure was below 135 pounds and stopping when accumulators were up to pressure).

The air for the diver was led through an air cooler (circulating water jacket) and through three Navy standard air separators before reaching the diver, the object being to cool the air and remove any oil fumes that might have been carried over from the pumps.

It was found that the air was sufficiently cooled coming from the accumulator, even with both compressors running without the cooler.

The piping from the accumulators was not exceedingly long (50 feet) and only one length of diving hose was used.

Under these conditions it was found that as long as the air pressure to the diver exceeded by 10 or 15 pounds the pressure to depth of which dive was made, sufficient air circulated through the helmet to attain ventilation equal to less than 1 per cent of an atmosphere of CO_2.

As there was no way of measuring the air supplied to the diver in the experimental diving tank, the only guide to air supply was the diver's well-being and per cent of CO_2 of the air from the diver's helmet. Air supply was always satisfactory in utilizing air from the accumulators. In ventilating the helmet with hand pumps air supply was not satisfactory at great depths, and the space and number of men required were great.

In the actual diving tests from the U. S. S. *Walke* a slightly different arrangement of air supply was followed. Air was supplied to the diver from a small (2 cubic feet) low-pressure accumulator, reaching this from torpedo (11 cubic feet) air flasks at high pressure, 2,500 pounds to the square inch. A reducing valve was interposed in the piping from the high-pressure accumulator to the low-pressure accumulator.

A high-pressure air compressor discharging into one of the torpedo air flasks was kept going, so that there could be no possibility of failure of air supply. With six torpedo air flasks on the U. S. S. *Walke* it is evident that air for deepest attainable depths for a long period of time could be supplied.

The capacity of the charging pump was rated at 15 cubic feet per hour, or one-fourth cubic foot per minute, at 2,500 pounds.

As 2,500 pounds equal 170 atmospheres excess pressure, $\frac{1}{4} \times 171$ equals 42 cubic feet of air measured at atmospheric pressure, rated capacity of pump per minute.

In the record dive from the U. S. S. *Walke* of 274 feet, or 8.3 atmospheres excess pressure, it is evident that in furnishing 4.5 cubic feet per minute, or 4.5×9.3, this equals 41.75 cubic feet. The power compressor would be just about able to supply air for one diver for this depth. In actual experience, however, it was found that more air was used than the compressor supplied.

This was thought to be due to—

A. The compressor not running to its full theoretical capacity.

B. Leaks in the line, as 175 pounds pressure had to be maintained on the low-pressure accumulator.

C. The air coming direct from the compressor was uncomfortably warm, and the diver, thinking it due to CO_2, took more air than was necessary, or the possibility of a low percentage of CO_2 in the air from the compressor necessitated a greater air supply.

It was found in this dive that a pressure of 50 pounds excess pressure on the low-pressure accumulator was necessary (above the pressure of sea water at depth of dive) to supply necessary air for ventilation of the diver's helmet.

In utilizing air for accumulators the following conditions are necessary:

A. The air in the accumulator must be free from noxious fumes and as near standard purity as possible, i. e., contain as near 0.04 per cent CO_2 as practicable. In utilizing air from the high-pressure accumulators it must be remembered that the air in the cylinders of the compressors is greatly heated in charging the accumulators, and oil with a high flashing point must be used, castor oil, if possible, so that no flashing in the cylinders will take place, producing CO and CO_2. If practicable, air analysis should be done.

B. Sufficient pressure in the low-pressure accumulator above the water pressure (depth of dive) must be maintained to insure proper circulation of the helmet. This is estimated between 25 and 50 pounds, according to the depth of the dive.

C. Reserve air supply must always be maintained in case of accident to compressor, etc., to insure a proper stage decompressor for the diver.

DIVER'S PARALYSIS, OR CAISSON DISEASE.

The cause of caisson disease is the liberation of bubbles of nitrogen in the various body tissues upon a decrease of pressure, i. e., ascending too rapidly from deep depths to the surface.

From a study of the gases of the blood and alveolar air it is found that nitrogen is absorbed by the blood mechanically according to the law of partial pressures.

The volume of a given gas dissolved by a liquid varies directly as the pressure (temperature remaining constant).

The oxygen is absorbed by the blood in loose chemical combinations with the proteids. Any increase of oxygen pressure does not increase the amount taken up chemically by the blood. It is found, however, that above the usual one-fifth of an atmosphere exerted by the oxygen extra oxygen is taken up by the blood according to the law of partial pressures.

The CO_2 pressure in the alveolar air, according to Haldane, with proper ventilation is constant (see "Helmet ventilation") and may be stated as about $\frac{5.6}{\text{atmospheres abs. pressure}}$ per cent CO_2. The CO_2 absorption by the blood is not well understood. A small amount is in physical solution with the blood but the greatest is held in some loose combination with the proteids, etc. With proper ventilation the CO_2 pressure is constant and does not change, and hence does not enter into the causation of caisson disease.

According to the law of partial pressures, considering the alveolar air as exerting a pressure of 20 per cent and in nitrogen 80 per cent of the total pressure, the volume of each 1,000 c. c. of blood may be figured as follows: The coefficients of absorption of the blood at body temperature are:

Nitrogen	0.013
Oxygen	0.0262

Considering that the usual alveolar CO_2 percentage of 5.6 becomes proportionately less with increased pressure, we may disregard it and consider that, roughly estimated, in deed depths at least, oxygen equals about 20 per cent alveolar air and nitrogen 80 per cent. According to this calculation the nitrogen in one liter of blood would equal $1{,}000 \times 0.013 \times 0.80 = 10.4$ c. c. at atmospheric pressure, or this increase in volume for every atmosphere excess pressure would be 10.4 c. c.×atmospheres absolute pressure.

The oxygen in solution (physical) $1{,}000 \times 0.0262 \times 0.20 = 5.24$ c. c. for each atmosphere of excess pressure of air, i. e., for every atmosphere excess pressure.

One liter of blood contains 5.24 c. c. oxygen measured at atmospheric pressure with every atmosphere excess pressure.

With the use of the Navy type of suit and method of supplying air to the diver it is considered that the oxygen absorption does not enter into the causation of caisson disease; that some of the oxygen is absorbed and utilized by the tissues, and that the oxygen being at one-fourth the partial pressure of the nitrogen it is given off much more rapidly on release of pressure. It is considered that nitrogen is the only gas that enters into the causation of caisson disease under these conditions. Typical lesion bubbles of oxygen in spinal cord of mice have been demonstrated in using a very high oxygen pressure, i. e., pure oxygen gas under high pressure and releasing the pressure suddenly.

The accepted theory of cause of caisson disease is that bubbles of nitrogen are liberated in the various tissues of the body, including the blood. The blood in the lungs being in contact with alveolar air takes up nitrogen in physical solution. The circulation time has been calculated at one minute, hence, the entire blood will be saturated for the partial pressure of nitrogen in one minute.

If the blood were the only tissue of the body to be considered it is evident that saturation and desaturation would take place in one minute. Such is not the case, however. The nitrogen in solution is given off to the various tissues and these, absorbing nitrogen, become saturated for that pressure after a period of exposure of about four hours (in man). With work, the circulation being increased, saturation takes place much more quickly (less than half the time). The blood of an average man is about 3 liters, or one-twentieth the body weight. In the first minute the blood, becoming immediately saturated, loses 95 per cent of its nitrogen in giving off the supersaturated nitrogen to the tissues. In returning to the lungs again (1 minute circulation) it will be 5 per cent saturated. The second minute, $\frac{5}{100} \times \frac{95}{100}$, or 4.75; and the third minute will add $\frac{5}{100}\times\frac{90.25}{100}=4.3$, etc. Thus in five minutes the tissues will become saturated at this rate.

5.0+4.75+4.5+4.3+4.1=22.65 per cent saturation of the body in five minutes.

Figuring at this rate, it is estimated that half saturation would take place in about 15 minutes, and the body would be entirely saturated in about one hour. Such is not the case, however. The blood is not equally distributed through the body. The connective tissues, skin, joints, medullated nerve trunks, etc., having a poorer blood supply than muscles, digestive organs, etc., will be the last to become saturated and the last to desaturate after becoming saturated.

It has been estimated that one-half saturation takes place in man in about one hour and total saturation in about four hours; according to Hill, with hard work, in half this time.

With a sudden decrease of pressure (high) to normal it is evident that the nitrogen in solution at low pressure will be immediately liberated, as in the soda-water bottle, and form bubbles. Such is the case with the diver, but the bubbles are formed much more slowly, and it may take some hours to increase in size necessary to cause symptoms.

It is known that nitrogen is five times more soluble in fats than in the other tissues of the body. It is given off more slowly from the fats and this accounts for the spinal cord lesions and lesions in the epiphyses of the bones, causing pains referable to joints in caisson disease. This also accounts for fat men being more predisposed to it.

Desaturation takes place at the same rate as saturation; hence if it takes a man four hours to saturate for a given pressure it will take four hours for him to desaturate.

It has been found that a man can become saturated for one atmosphere excess pressure and have pressure immediately reduced to normal without any ill effects whatsoever. In fact, a little higher pressure than this can be stood; i. e., saturation at 2.3 absolute pressure and decompressed to atmospheric pressure, or a ratio of 2.3 to 1. It is considered that the bubbles of nitrogen that are liberated are so fine as to pass through the finest capillaries and cause no damage or danger to the diver's well-being. On this theory have been constructed a series of tables, based on what is known as stage decompression (in contrast to slow or uniform decompression); that is, a change of absolute pressure to a reduced pressure, so that absolute pressure will be to this reduced absolute pressure as 2 to 1, or 2.3:1. Example: A diver working at 165 feet, or 5 atmospheres excess pressure or 6 atmospheres absolute. According to this theory, absolute pressure diminished to 2.6 atmospheres; i. e., 6:2.6, equals 2.3:1.

As we have the atmosphere exerting 1 atmosphere pressure, the diver can be safely brought up to an excess pressure of 1.3 atmospheres a depth from the surface of 43 feet. Upon this theory there has been constructed an excellent system of tables, the man coming quickly from deep and dangerous pressures to comparatively shallow depths with the various stops at every 10 feet.

It has been found that decompression in this manner is far safer after short exposures than a gradual decompression; i. e., going slowly up to a slow pressure. With uniform decompression the diver instead of desaturating continues to absorb more nitrogen for the higher pressures. Decompression tables as practiced by the British Admiralty follow:

TABLE 1.—*Decompression tables (used in the British Navy) showing ordinary time limits in deep water; stoppages during ascent.*

Depth.		Pressure in pounds per square inch.	Time under water; i. e., from surface to beginning of ascent.	Stoppages in minutes at different depths.						Total time for ascent in minutes.
Feet.	Fathoms.			60 feet.	50 feet.	40 feet.	30 feet.	20 feet.	10 feet.	
0-36	0-6	0-16	No limit							0-1
36-42	6-7	16-18½	Up to 3 hours							1-1½
			Over 3 hours						5	6
42-48	7-8	18½-21	Up to 1 hour							1½
			1 to 3 hours						5	6½
			Over 3 hours						10	11½
48-54	8-9	21-24	Up to ½ hour							2
			½ to 1½ hours						5	7
			1½ to 3 hours						10	12
			Over 3 hours						20	22
54-60	9-10	24-26½	Up to 20 minutes							2
			20 minutes to ¾ hour						5	7
			¾ to 1½ hours						10	12
			1½ to 3 hours					5	15	22
			Over 3 hours					10	20	32
60-66	10-11	26½-29½	Up to 15 minutes							2
			¼ to ½ hour						5	7
			½ to 1 hour					3	10	15
			1 to 2 hours					5	15	22
			2 to 3 hours					10	20	32
66-72	11-12	29½-32	Up to 15 minutes						2	4
			¼ to ½ hour					3	5	10
			½ to 1 hour					5	12	19
			1 to 2 hours					10	20	32
72-78	12-13	32-34½	Up to 20 minutes						5	7
			20 to 45 minutes					5	15	22
			¾ to 1½ hours					10	20	32
78-84	13-14	34½-37	Up to 20 minutes						5	7
			20 to 45 minutes					5	15	22
			¾ to 1½ hours					10	20	32
84-90	14-15	37-40	Up to 20 minutes					3	5	10
			20 to 40 minutes					5	15	22
			40 to 60 minutes				3	10	15	30
90-96	15-16	40-42½	Up to 20 minutes					3	5	11
			20 to 35 minutes					5	15	22
			35 to 55 minutes				5	10	15	32
96-108	16-18	42½-48	Up to 15 minutes					3	5	11
			15 to 30 minutes				3	7	10	23
			30 to 40 minutes				5	10	15	33
108-120	18-20	48-53½	Up to 15 minutes				2	3	7	15
			15 to 25 minutes				5	5	10	23
			25 to 35 minutes				5	10	15	33
120-132	20-22	53½-59	Up to 15 minutes				2	5	7	17
			15 to 30 minutes				5	10	15	33
132-144	22-24	59-64½	Up to 12 minutes				3	5	5	16
			12 to 25 minutes			2	5	10	12	32
144-156	24-26	64½-70	Up to 10 minutes				3	5	5	16
			10 to 20 minutes		2	3	5	8	10	31
156-168	26-28	70-75	Up to 10 minutes			2	3	5	5	18
			10 to 16 minutes		2	3	5	7	10	30
168-180	28-30	75-80½	Up to 9 minutes			2	3	5	5	18
			9 to 14 minutes		2	3	5	7	10	30
180-192	30-32	80½-86	Up to 13 minutes		2	3	5	7	10	30
192-204	32-34	86-91½	Up to 12 minutes	2	2	3	5	7	10	32

TABLE 2.—*Decompression tables (used in the British Navy) showing stoppages during ascent after exceeding the ordinary limits of time on the bottom.*

Depth.		Pressure in pounds per square inch.	Time from leaving surface to beginning of ascent.	Stoppages at different depths in minutes.								Total time for ascent in minutes.
Feet.	Fathoms.			80 ft.	70 ft.	60 ft.	50 ft.	40 ft.	30 ft.	20 ft.	10 ft.	
66	11	29½	Over 3 hours	....	....	....	....	....	....	10	30	42
72	12	32	2 to 3 hours	....	....	....	....	....	....	10	30	42
			Over 3 hours	....	....	....	....	....	....	20	30	52
78	13	34½	1½ to 2½ hours	....	....	....	....	....	....	20	30	52
			Over 2½ hours	....	....	....	....	....	....	30	30	62
84	14	37	1¼ to 2 hours	....	....	....	....	....	....	15	30	47
			2 to 3 hours	....	....	....	....	....	5	30	30	67
			Over 3 hours	....	....	....	....	....	10	30	35	77
90	15	40	1 to 1½ hours	....	....	....	....	....	5	15	25	47
			1½ to 2½ hours	....	....	....	....	....	5	30	30	67
			Over 2½ hours	....	....	....	....	....	20	35	35	92
96	16	42½	55 minutes to 1½ hours	....	....	....	....	....	5	15	30	57
			1½ to 2½ hours	....	....	....	....	....	10	30	35	72
			Over 2½ hours	....	....	....	....	....	30	35	35	102
108	18	48	40 minutes to 1 hour	....	....	....	....	....	10	15	20	48
			1 to 2 hours	....	....	....	....	5	15	25	35	83
			Over 2 hours	....	....	....	....	15	30	35	40	122
120	20	53½	35 minutes to 1 hour	....	....	....	....	5	10	15	25	57
			1 to 2 hours	....	....	....	....	10	20	30	35	97
			Over 2 hours	....	....	....	....	30	35	35	40	142
132	22	59	½ to ¾ hour	....	....	....	....	5	10	15	20	53
			¾ to 1½ hours	....	....	....	5	10	20	30	30	98
			Over 1½ hours	....	....	....	15	30	35	40	40	163
144	24	64½	25 minutes to ¾ hour	....	....	....	3	5	10	15	25	61
			¾ to 1½ hours	....	....	....	10	10	20	30	35	108
			Over 1½ hours	....	....	....	30	30	35	40	40	178
156	26	70	20 to 35 minutes	....	....	....	3	5	10	15	20	56
			35 minutes to 1 hour	....	....	....	7	10	15	30	30	95
			Over 1 hour	....	....	20	25	30	35	40	40	193
168	28	75	16 to 30 minutes	....	....	....	3	5	10	15	20	56
			30 minutes to 1 hour	....	....	3	10	10	15	30	30	101
			Over 1 hour	....	5	25	25	30	35	40	40	203
180	30	80½	14 to 20 minutes	....	....	....	3	3	7	10	15	41
			20 to 30 minutes	....	....	2	2	3	10	15	25	60
			30 minutes to 1 hour	....	3	3	7	10	20	30	35	111
			Over 1 hour	....	15	25	30	30	35	40	40	218
192	32	86	13 to 20 minutes	....	....	....	3	3	7	15	15	46
			20 to 30 minutes	....	....	3	3	5	10	15	25	64
			30 minutes to 1 hour	....	3	5	10	12	20	30	35	118
			Over 1 hour	5	20	25	30	30	35	40	40	228
204	34	91½	12 to 20 minutes	....	....	3	3	5	7	10	20	51
			20 to 30 minutes	....	3	3	3	5	10	20	20	67
			30 minutes to 1 hour	3	3	5	10	15	20	30	35	124
			Over 1 hour	15	20	25	30	30	35	40	40	238

These tables were constructed and proved by careful animal experimentation by Haldane. While they are not guaranteed to protect from a slight or moderate attack of the "bends," a diver compressed according to them will be saved from any serious attack of caisson disease. It is recommended that they be incorporated in the new Diving Manual.

After complete saturation stage decompression becomes less efficient, and it is questionable whether uniform or stage decompression has the greater advantage. With short exposures, however, stage decompression is safer. But it is simply a question of time allowance in either case.

It is evident that these tables consume a large part of the time in shallow water. As there is one increase in volume of gas from 33 feet to the surface it is evident that these protracted stays are most essential, as the danger point of large bubble formation is doubled.

It is evident that if a diver saturates and desaturates at the same rate, decompression will be in proportion to compression and length of exposure to high pressure. Hence, in deep diving it is to the diver's advantage to descend as quickly as possible, limit his stay to as short a time as possible, and then hurry out to his first stage of decompression. Some of the divers engaged in these tests have taken a pressure equal to 212 feet in from 40 to 60 seconds.

In all our diving tests the decompression tables as recommended by the British Admiralty were followed and in deep depths tables on the same theory for the increased depths utilized.

No symptoms of the mildest case of caisson disease were noted. It might be stated that no dives longer than 30 minutes were made at extremely high exposures, and the diver was usually at rest. On two occasions, however, by hurrying out too rapidly mild cases of the "bends" were experienced. In both instances the first thing that was observed was a burning dermatitis (sand hog's itch) over the entire body, due to nitrogen bubbles in the skin and subcutaneous tissues, followed in a few hours by twinges of pain in the various joints.

Under the usual conditions decompression can not be hurried with safety. Muscular exercise increases circulation and hurries desaturation. This is necessary and is taken into account in the construction of the tables.

By decreasing the partial nitrogen pressure in the diver's helmet and by supplying oxygen to the diver we hasten desaturation greatly, and this could be used very advantageously in shallow depths. It must be remembered, however, that moderate oxygen pressures are dangerous and if high will cause death quickly from oxygen poisoning. Two hundred per cent oxygen pressure is risky, increasing with length of exposure, and 300 per cent extremely dangerous for any length of stay, however short. (See "Oxygen poisoning.")

As oxygen and nitrogen pressure increases proportionately with depth, it is evident that in using air at 10 atmospheres absolute pressure will have oxygen exerting 200 per cent of an atmosphere and nitrogen 800 per cent of an atmosphere.

Nitrogen is absorbed in increasing amounts and predisposes to caisson disease, necessitating a longer decompression.

If it were possible to introduce some diluting inert gas to decrease the partial pressure of oxygen and nitrogen, it is evident that greater depths, with safety from oxygen poisoning, could be attained, and at the same time the partial pressure of nitrogen would be diminished. Absorption of nitrogen by the body, with consequent danger of caisson disease, would be lessened, and a shorter decompression period in proportion to the nitrogen saturated could be established.

Now that diving with use of high-pressure accumulators has proved practicable, if air diluted with some inert gas could be supplied the diver in place of air, i. e., as hydrogen and air, both conditions would be met. This is a new field suggested but would necessitate a larger amount of animal experimentation before its practical use could be determined.

It is evident from the preceding that the only effective treatment for caisson disease would be immediate recompression. In all caisson work medical air locks, or recompression chambers, are installed in connection with the work for this purpose.

In the experimental diving from the U. S. S. *Walke* a recompression chamber was installed and air supply from a torpedo air flask was utilized. It was found that one flask would charge the chamber to 100 pounds in less than three minutes. The chamber was installed with medical means for treating any case of caisson disease that might occur, especially with the possibility of accidental "blowing up." Fortunately, no such cases occurred. In all cases of deep-diving operations it is considered that a compression chamber of some sort is essential, as there are no efficient means of treating bed cases of caisson disease without one. Immediate recompression usually alleviates all symptoms. If some time has elapsed after onset of the attack, however, while it may help, it is not as efficacious as immediate compression at onset of symptoms.

EFFECTS OF OXYGEN PRESSURE.

Paul Bert, in his experiments on the cause of death of animals inclosed in a small space, found that—

1. At pressures inferior to 1 atmosphere, when the CO_2 is absorbed by potassium hydrate, sparrows live until the partial pressure of oxygen sinks to 3.6 per cent of an atmosphere.
2. In air compressed to 2 to 9 atmospheres and superoxygenated to prevent want of oxygen, they die when the pressure of CO_2 equals 26 per cent of an atmosphere.
3. In higher pressure death is caused by the pressure of oxygen, and rapidly when this equals 300 to 400 per cent.
4. In pressures of 1 to 2 atmospheres death is due partly to fall of oxygen pressure and partly increase of CO_2.

In pressures of 3 to 4 atmospheres of air the poisonous effects of oxygen begin to appear after long exposures.

Air composed of 20 per cent oxygen exerts one-fifth of an atmosphere oxygen pressure. At 10 atmospheres' pressure, the oxygen being one-fifth, would exert 2 atmospheres of oxygen pressure. Hence 2, 3, 4 atmospheres of oxygen pressure would equal 10, 15, and 20 atmospheres of air.

The experiments of Bert were carefully worked out by Smith and Hill, and these investigators found that exposure of animals to a pressure of 170 to 180 per cent of an atmosphere of oxygen caused, in a short time, diminution in the power of the lungs to absorb oxygen. The tissues of the lungs showed intense congestion and an exudate into the alveolæ.

According to Hill, high partial pressure of oxygen produces a marked irritant effect on the lungs, producing first congestion and shortly afterwards hemorrhagic exudation and consolidation, i, e., a typical pneumonia. The pneumonia is patchy, if quickly developed and general if slowly developed.

According to Smith it requires about 24 hours' exposure at plus 7 atmospheres of air or 168 per cent atmospheres of oxygen to produce marked symptoms of pulmonary congestion.

Experiments on monkeys showed no lung trouble in sequent exposures every day for four or five hours at a time.

With exposures to oxygen pressure of 300 to 400 per cent, symptoms of oxygen poisoning quickly intervene, and, in addition to the lung irritation, convulsions tetanic in character may occur.

In most types of self-contained diving and submarine-escape apparatus oxygen is used in addition to air. It is evident from the above that their construction and use will depend on the findings of Bert.

The simplest type of self-contained apparatus is the usual mine-rescue apparatus. This is constructed for work in one atmosphere, and the question of oxygen poisoning does not enter. The question of deficient oxygen pressure and CO_2 does often enter.

This apparatus is constructed so that oxygen is supplied from a small high-pressure accumulator, usually at the rate of 2.5 liters per minute. Air expired is forced through a chamber or cartridge containing caustic soda (solid), which removes most of the CO_2. A small canvas sack acts as a low-pressure accumulator, and the air is rebreathed, but oxygen is constantly being supplied at the rate of 2.5 liters a minute, the high-pressure accumulator holding about one hour's supply of oxygen. With failure of oxygen supply with this type of apparatus it is evident that with CO_2 removed and oxygen diminished, in partial pressure it would not be long before effects of diminished oxygen pressure became manifest. Such is the case, and men often become unconscious in these suits before they realize that anything is wrong.

It has been found in the use of these suits that more than 2.5 liters of oxygen per minute are utilized in hard work. While a man may sit and move around slowly in this apparatus, when it comes to walking and doing moderately hard work his oxygen supply is entirely too little, and unless he sits quietly he will become unconscious and be in danger of losing his life. The country has been flooded with a great many of these outfits, which, on being put to a real test, have proved absolutely useless, and there are many instances where men have lost their lives in their use.

Siebe-Gorman, in the construction of mine-rescue apparatus, in work for fire fighting, found that it was necessary to supply 3 liters of oxygen per minute to permit a man to climb a ladder.

Another type of apparatus similar to this type has been constructed. Instead of oxygen being supplied by an accumulator it is supplied by decomposition of fused sodium peroxid.

$$NA_2O_2+H_2O=2NAOH+O.$$

Moisture from the expired air usually is used in liberation of oxygen, and the resulting NAOH absorbs the CO_2.

$$2NAOH+CO_2=NA_2CO_3+H_2O.$$

It is evident that both these types of apparatus depend entirely on sufficient removal of CO_2 from the expired air and sufficient supply of oxygen.

Breathing with these types is usually through a mouthpiece and necessitates practice in use.

These principles have been applied to diving apparatus and submarine-escape apparatus. It is known as the noninjector type in contradistinction to the injector type. The noninjector type (Siebe-Gorman) was tried in our experiments. Instead of using pure oxygen a 50 per cent mixture of oxygen and nitrogen was used and the apparatus limited to diving to 66 and 70 feet of water, i. e.,

$\frac{50}{100}\times 1$ plus $\frac{66}{33}=150$ per cent atmospheres oxygen pressure, which is considered a safe oxygen pressure for fairly long exposures.

In this apparatus oxygen mixture was supplied at the rate of 5 liters a minute. In addition there is a special valve arrangement for inflating the suit sufficiently to prevent squeeze in descending.

In the Siebe-Gorman injector type of apparatus the diver expired into the helmet directly and arrangement was made for supplying oxygen mixture to the helmet and at the same time sucking air from the helmet through a cartridge of sodium hydrate back to the helmet. In this type a 50 per cent mixture of oxygen and nitrogen is used and the suit limited to depths of 60 to 70 feet, or an oxygen pressure of 150 per cent atmospheres.

A Draeger injector type of apparatus was also tried. This differed from the Siebe-Gorman type, in that descent was made by using air from a small high-pressure accumulator and pure oxygen supplied at the rate of 2.5 liters per minute. The suit was supposed to be good to depths of 200 feet and good for one hour's submersion.

Analysis of air in this type showed as high as 60 per cent of oxygen with varying percentages of CO_2. It is evident from this analysis that the suit could not be safely used in deep depths on account of the dangers of oxygen poisoning.

In the practical use of all these suits it was found that diving to depths of 60 to 70 feet could be done as readily with the ordinary diving apparatus, provided that the diver was at rest. When work was attempted, however, it was found that even moderate work could not be done without great respiratory distress.

Analysis of air showed varying percentage of CO_2 up to 4 per cent. Oxygen was always present in sufficient quantities, averaging about 40 per cent.

The use of these suits was not deemed practicable for the following reasons:

1. Their construction is complicated and they easily get out of order.
2. They are limited to moderate depths on account of danger of oxygen poisoning and CO_2 accumulation.
3. The air supply is limited to about one hour, and in case of fouling would mean death to the diver unless he were quickly cleared.
4. Hard work was not practicable on account of respiratory distress.
5. The superiority of diving with the use of air from hand-operated diving pumps or air accumulators (surface) was shown.

PHYSICAL STANDARD OF DIVERS.

In recruiting the Navy, men of high physical standard are chosen—i. e., men free from disease—with ears, heart, lungs, kidneys, and blood vessels normal, and men of good muscular development. It has been found that there are two other elements that enter into the selection of men for deep diving, viz: 1, degree of fatness; 2, age.

Hill, in a careful course of animal experimentation and a study of the statistics of caisson workers found that men of moderate robustness and men at or past middle age were more disposed to caisson disease than were the young, or the slim, small, wiry men.

From his experiments he is of the opinion that the fact most concerned is the amount of fat. This is explained by the fact that nitrogen is five times more soluble in the fats, and that it is given off more slowly; hence the predisposition to caisson disease.

Men of middle age are more inclined to fatness, and therefore more predisposed to caisson disease. The respiratory exchange in middle-aged men is slower, and in moderately fat men the blood, instead of being one-twentieth of the body in weight, is nearer one-thirtieth, and hence elimination of nitrogen in solution of body tissues would be slower—i. e., a proportion of 20:30 in slim young men as compared with moderately fat men.

Arteriosclerosis is considered a dangerous factor and men with even slight arteriosclerosis should not be chosen for this work.

Ear disease is considered a bar against diving, especially any trouble interfering with the patulousness of the Eustachian tubes. It was found in our work that ofttimes men with a slight cold and congestion of the Eustachian tubes were not able to clear their ears, i. e., equalize the pressure within the Eustachian tubes and the external pressure on the drums. The pain from excessive pressure on the drum is severe. Fortunately, the hardest part of the dive, in this respect, is the first 30 feet. If a diver makes his first 30 feet, he will be troubled little in this respect irrespective of the depth beyond.

If a man is suffering from coryza it is better to select another diver, as he will be able to descend much more quickly, and therefore lessen his exposure to high pressure and his liability to caisson disease.

As air pressures beyond three or four atmospheres have an irritant effect on the lungs it is evident that the diver's lungs must be sound and no latent foci of tuberculosis present.

It is considered that the best type of man for deep diving is the young (20 to 30), short, thin, wiry man. Circulation is faster in their case and they desaturate more quickly and are less inclined to caisson disease.

PREVENTION OF ACCIDENTS.

Diving as practiced at present in our Navy is a dangerous undertaking. Accidents are constantly occurring, even in diving to moderate depths.

From careful study of the accidents occurring it is found that the cause of most are as follows:

A. Lack of knowledge.
B. Insufficient training.
C. Defective apparatus.
D. Carelessness.
E. Insufficient care in selection of men.

Heretofore the diving manual issued for instruction of divers has been a most rudimentary affair and it does not include the real scientific facts relative to diving. It is considered that the first step to remedy this defect is the publication of a new, up-to-date, diving manual, and the supplying of it to officers and men, who may, at any time, become connected with any diving operations. Gunner G. D. Stillson, United States Navy, has already received orders to prepare a new diving manual and this will appear in a short while.

It is considered that the course of instruction in diving at the various Navy diving schools is insufficient and does not fit men for diving with safety, especially in moderately deep depths. This is a defect that can easily be remedied as follows:

(*a*) The installation of diving tanks similar to the experimental diving tank used at A. Schrader Son's; (*b*) the instruction of men in diving in these tanks, using hand pumps in series and air from air accumulators (high and low pressure); (*c*) all men to qualify in tank diving to depths of 170 feet for 15 minutes; (*d*) after the completion of the course in tank diving a course of instruction in actual diving, tending, etc., in open water; (*e*) all men to qualify in depths of 150 feet for 15 minutes before being graduated as qualified divers; (*f*) the course to include a thorough instruction of the diving apparatus, the function of the various parts, methods of testing, etc.

The present type of diving apparatus is considered defective in many ways. This subject has already been discussed and the improved type of apparatus recommended. It is also recommended that no more of the present type of diving apparatus be purchased. Specifications for the new type are being prepared and authority to purchase outfits of this type has been granted.

This does not mean that the subject of efficient apparatus is entirely solved. All diving apparatus is constantly deteriorating and imperfections from use and disuse are constantly occurring.

The maintaining of efficient apparatus is in proportion to the care it receives.

In all diving operations it is essential to test the apparatus just before using to be sure of its efficiency.

With the improved method of diving the simplicity and confidence in the newer method often leads to a disregard of safeguards, and an inclination to recklessness and carelessness on the part of men who do not realize the seriousness of the undertaking.

Tenders are apt to be negligent, and as a result accidents are likely to occur.

Diving is a serious undertaking and should be so considered. Caution and attention should always be observed on the part of all connected with the operations.

Heretofore diving in the Navy has practically been restricted to depths of 60 or 70 feet. In diving to this depth the ordinary physical standard as required was sufficient; that is, if a man was physically sound and strong he was considered suitable for diving.

In deep diving the question of a more careful selection on account of liability to caisson disease is to be considered.

A careful examination by the medical officer is essential. This examination should be made at regular intervals.

A safe plan of procedure is to have the medical officer examine all men detailed for the work before the diving is undertaken.

ACCIDENTS.

The accidents usually encountered in diving operations are:

1. Asphyxia.
2. Squeeze.
3. Caisson disease.
4. Accidental "blowing up."
5. Fouling.
6. Ear pains (bleeding from ears).
7. Bleeding from the lungs and nose.
8. Mechanical injuries from external violence.
9. Exhaustion.
10. Drowning.
11. Oxygen poisoning.

Asphyxia: This is usually the result of insufficiency or failure of air supply. This has already been discussed and needs no further comment.

Squeeze: In cases of slight squeeze, as with the regulating escape valve open wide and a minimum air supply, the air within the air passages is at a lower pressure than the pressure without, and the diver is forced to breathe against this extra pressure. Respiratory embarrassment results in a short while, and often a diver struggling up his descending line, buoyance being negative, under these conditions may bleed considerably from the lungs and nose. Hemorrhage in this case is usually due to rupture of small lung capillaries.

Squeeze is usually the result of an accidental fall. This has already been explained. It may occur from other causes, however.

1. A diver descending ahead of his air supply; i. e., descending before the pressure within the suit is equal to the water pressure without.
2. Failure of air supply and a leaky inlet valve (check).
3. Ruptured cuff of dress and the diver throwing his hand up over his head. Squeeze in this case being slight but enough to interfere with respiration.)

N. B.—The tender should always have a tight hold on the diver's lines to prevent his falling.

Caisson disease: This has been explained. Its prevention consists of:

1. Limiting time of exposure to high pressures.
2. Proper stage decompression.
3. Proper physical standard in selection of divers.

Accidental blowing up: This may be injurious in various ways, as:

From deep depths an acute attack of caisson disease may result, or from any depth the danger of striking some floating object, as ship's side, etc., with resulting mechanical injury.

This is caused by overinflation of dress, or the drag of tide on the lines, etc., sweeping the diver to the surface.

Fouling: Lines become entangled in working about wrecks and prevent the diver from ascending. This usually requires another diver's going down and clearing the one fouled.

Divers should be instructed in this respect. Deaths have resulted with men fouled and unable to ascend.

Ear pains: These are due to inequalities of pressure on the sides of the drums, usually due to inexperience, the diver not knowing how to "clear his ears." Cases have been recorded where pressure (external) has been sufficient to rupture the drums and cause bleeding.

Mechanical injuries from external violence: These are of many varieties and call for no special comment.

Exhaustion: Deaths from exhaustion in diving have occurred.

Drowning: Two cases on record of drowning have occurred. In both instances the helmet became detached from the suit. It is a common superstition among divers that if the dress ruptures drowning results. Such is not the case. The dress is not an essential part of the apparatus. Diving with helmets secured to the body has been done in depths to 140 feet as readily as with the dress and helmet.

As long as the air pressure within the helmet is maintained water can not enter and the diver will not drown. By simply closing the escape valve air is forced down into the suit and will escape at the site of the rent.

Oxygen poisoning: There are no recorded cases. With the usual method of diving sufficient depths of long enough periods of time have not been attained to cause this effect.

On using self-contained diving apparatus and submarine-escape apparatus this question has an important bearing and has been considered.

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